ENGINEERING A PRIMARY WASTE TREATMENT PLANT

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ABSTRACT

This thesis deals with the design and construction of a primary waste treatment plant. The scope of work covered here, includes waste sampling and characterization, process design data gathering, process and mechanical design, cost estimate, and a general discussion of the construction and start-up.

In the development of this work, it is assumed that a decision has been made to build the waste treatment plant, using a known process. Therefore, economic evaluations designed to determine return on investment and selection of a process, will not be discussed. The impact the capital investment associated with the waste treatment facility has on the overall production costs of the basic product oriented facility, is discussed.

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CHAPTER 1

INTRODUCTION

The type of treatment given to an industrial waste water, depends on various factors which include the nature of the waste water and its determined end use. For example, industrial waste waters discharged into public waterways, must meet federal and state quality criteria to preserve wild aquatic life and to render the water fit for municipal water consumption. On the other hand, waste water destined for reuse in the process industries does not require such elaborate treatment.

Primary Waste Treatment Methods

In primary waste treatment methods, the waste water is generally given both physical and chemical treatments. The physical treatment of the waste water, is employed to remove floating solids or liquids (oils), suspended solids and settleable suspended solids. This is usually achieved in a settling basin or pond. The chemical treatment of the waste water, usually follows the physical treatment and it is used essentially to adjust effuent pH to precipitate heavy inorganic metal ions.

The physical treatment methods commonly used, include a) pretreatment ahead of sedimentation by screening, degritting and waste water surface sweeping to remove floating solids and oils, b) clarification to remove settleable solids which impart turbidity to waste waters, c) flocculation to agglomerate finely divided settleable solids, d) flotation by air to remove solids and material with low settling velocities, e) gravity separators to remove insoluble liquid contaminants, f) filtration to remove suspended impurities which generally do not settle easily and g) absorption with activated carbon medium to remove color, odor, turbidity and some organic contaminants measured in terms of BOD*. The choice of the physical treatment method employed, is determined purely by the characteristic of the waste and, to some extent, the cost of the treatment method.

Chemical treatment methods on the other hand, are designed mainly to remove undesirable dissolved solids. Chemical treatment methods are increasingly becoming important in treating all types of waste waters. In primary treatment methods, neutralization with an acid or alkali to precipitate the inorganic ions in the form of their insoluble salts or hydroxides, is the method most frequently used. In some cases, the neutralization step is followed by addition of coagulating agents like polyelectrolytes (inorganic polymers) to promote agglomeration of colloidal particles and facilitate their removal by filtration or sedimentation. Other chemical treatment methods like ion exchange membrane filtration, oxidation-reduction, electrodialysis and reverse osmosis, are selective to some extent and expensive. These find applications in secondary and terciary

*BOD - Biological oxygen demand. It is a measure of the degree of organic contamination.

treatment methods designed mainly to remove organic contaminants and to recover certain valuable contaminants in waste waters.

Waste Collection

Collection of waste waters for central treatment facility, is an important step in designing a treatment system. This is because, an indiscriminate mixing of all waste sources could result in the treatment of unnecessary large volumes of waste water which not only increases the cost of the treatment facility but also reduces the effectiveness of removing the undesirable contaminants. Therefore, all sources of the waste waters must be characterized and appropriate segregation of the waste carried out.

The waste can be segregated on several bases:

a) Contaminated and uncontaminated.

b) Organic and nonorganic.

c) Acidic and basic.

d) Strong and dilute.

and thus, an appropriate sewer system is designed to carry the waste waters to one or more treatment facilities.

Quite often however, this segregation is a very difficult task especially in very old process plants where there are no drawings for the sewer network and generally several sources join before going to an outfall. In such cases, dye tracing and physical digging to identify individual sources, seem to be the only solution.

The design of a sewer system to carry waste waters, is similar to that of process plant except that the waste water is channelled to a central settling basin or pond, and man holes and catch basins are used more frequently for changes in direction and elevation especially in gravity flow sewer systems. The conduit materials commonly used are FRP (fiberglass reinforced plastic) and vitrified clay because these are inert to most corrosive agents especially in the concentrations encountered in waste waters.

In the design of the sewer systems, a high safety factor (30-50%) is commonly used to allow for accommodation of new contaminated sources due to process plant expansion or contaminated storm waters excluded during initial design but must now be included. Usually reasonable savings are achieved in the treatment facility by selectively containing surface areas in the process plant which are potential sources of contaminated storm waters. Thus materials handling areas where potential spills can occur, rotating equipment bays where packings and glands could leak and process areas where atmospheric discharges occur, are preferably curbed and channelled to a waste water treatment sewer.

Treatment Facility

The primary treatment facility, consist of: a) the settling basins, b) the neutralizers, c) clarifiers, d) dewatering equipment and e) effluent monitoring stations.

<u>The settling basins</u> (also called equalization basins) form a very important step in the treatment of waste waters. On account of their large storage capacities, they serve to smoothen hydraulic and concentration surges originated by changing process conditions like process upsets, increased production rates, equipment washings etc. Thus by smoothing out the waste water surges, a constant volume and concentration is fed to the treatment facility and control problems, especially those associated with pH are reduced. The settling basins are usually designed to hold waste waters generated within a period of 24 to 48 hours. To allow for maintenance (mainly sludge removal), the settling basins are usually built in pairs operated in parallel. As a general rule, the settling basin is rubber lined to prevent contamination of ground waters.

<u>The neutralizers</u> are open top stirred tanks. It is here that the acid or alkali (depending on whether the waste is alkali or acidic) is added to precipitate the heavy inorganic metal ions as their insoluble salts or hydroxides. The choice of the neutralizing agent, depends on its cost, availability, ease of handling and its effectiveness is precipitating the contaminant.

Acid waste waters are commonly neutralized with lime because it is economical. However, lime presents a lot of problems. Slaking equipment is required to bring the lime into solution, therefore initial capital investment is high. It also forms insoluble salts with most strong acids and therefore large volumes of sludge are produced which must be handled for disposal. On the other hand, caustic soda (sodium hydroxide) which has none of these problems, is more expensive to used. However, it reacts a lot faster than lime and therefore, lower retention time can be used and the neutralizers are therefore smaller in capacity. Both lime and caustic soda, have comparable effectiveness in removing heavy metal ions and therefore the choice of one or the other, is based on economic evaluations, handling problems and availability. Other alkali agents used sometimes to neutralize acidic waste waters, include soda ash (sodium carbonate) and ammonia, but they are not effective in precipitating the heavy metal ions. Alkali waste water, are usually neutralized with sulfuric acid.

In the design and operation of neutralizers, the major problem, is pH control. The pH of a solution is a logarithmic function of hydrogen ion concentration and it increases in increments of 10. Therefore in the vicinity of the neutralization point, the pH control is difficult. At least two neutralizers in series are used, with a rough pH control in the first and final pH adjustment in the second. Very commonly, three neutralizers are used in series with the middle one serving mainly to ensure complete reaction of the neutralizing agent added in the first before the third neutralizer is reached for final adjustment. This arrangement prevents pH overshooting.

The clarifiers serve to remove the precipitated metal ions in the neutralizers. In general, the solution leaving the neutralizers for the clarifiers, is colloidal and the settling velocity of the suspended solids, is low. Various chemical flocculating agents are added to promote particle coagulation and agglomentation and thus increase the settling velocity of the particles. Common flocculating agents used include salts of iron and aluminum and many organic polymers like polyamides.

Clarifiers are designed on the basis of surface loading rate expressed as gallons per day per square foot of horizontal area. The values of the surface loading rates range from a low of 400 gallons per day per square foot for untreated waste waters to a high of 1200 gallons per day per square foot for well flocculated waste water. In primary waste treatment design, the surface loading rate is usually between 600 and 900 gallons per day per square foot. Many states regulate the surface loading rate since the clarity of the effluent generally descreases with increasing surface loading rates. Another important design parameter of the clarifier, is retention time. Particle flocculation occurs due to eddying motion of fluid which promotes particle collision and coalescence. The rate of collision and coalescence, is a function of particle concentration and the ability, of the particles to coalesce on collision. The number of collisions and coalescences, increases with time hence retention time in clarifiers is also an important design consideration. The retention time is usually determined by the depth of the clarifier once the surface area has been determined from the surface loading. Common depths and retention times used in primary waste water treatments are:

Surface loading gal/day/sq. ft.	Retention time, hr. Depth ft.				
	6	7	8	9	10
600	1.8	2.0	2.2	2.8	3.0
800	1.5	1.6	1.8	2.1	2.2
900	1.4	1.5	1.6	1.9	2.0

Table 1 - Clarifier Design Parameters

The above depths, are those required for quiescent settling and in cases where the clarifier is required to have sludge storage capacity, additional allowance in depth must be included.

Dewatering equipments are required to reduce the volume of the sludge produced in the clarifiers and thus reduce sludge disposal cost. Vacuum filters and centrifuges are the most common dewatering equipments used in primary waste water treatment facilities. Mixed bed filters are sometimes used but because of the additional problems with handling the backwash water solids, they find limited application.

A vacuum filter system, consists of a drum mounted in a trough, the drum drive mechanism, vacuum pump and vacuum receivers, water wash pump and a precoat solution tank and pump. The various filter aids used, are for prolonging the filtering cycle. In general, sludge produced in a primary treatment facility, is collodidal and in effect, it plugs the pores of the filter screen. A filtering aid like a precoat is applied on the filter screen and as the screen rotates a knife scrapes off the cake and a tiny layer of precoat. Every 4 to 6 hours, this layer of precoat has to be reapplied on the screen.

A centrifuge on the other hand, is a high velocity equipment which effects solid separation by a centrifugal force. In the solid bowl type of centrifuge which is the type most commonly used, the sludge is fed into the rotating bowl at constant feed rate and the solids settle through the liquid to the wall of the bowl where it is compacted by the centrifugal force and is discharged through an internal screw conveyor. The centrate is discharged by displacement through the opposite end of the centrifuge.

In the design of vacuum filters and centrifuges, the most important parameters are the solid content of the sludge to be dewatered (optimum contents is 6 to 10%), the sludge consistency and the type of sludge. Varying these parameters, varies the performances of the dewatering equipment. With centrifuges, the capacity, moisture content of the cake and the clarity of the centrate, can be varied by varying the speed of the bowl, feed rate and retention time in the bowl. With vacuum filters, the same parameters can be varied by varying the percentage submergence of the drum and the speed of the drum.

The choice between a vacuum filter and a centrifuge is based on, a) installed and operating cost, b) desired moisture content of cake, c) clarity of filtrate/centrate, d) space requirements. In general, vacuum filters produce wetter cakes and clearer filtrates than centrifuges but they require more installation space and are more expensive to operate. On the bases of installed cost, the centrifuge is slightly more expensive. The final choice however, is highly influenced by sample test runs in the vendor's shop.

Effluent Discharge

The clarified overflow from the primary waste treatment, must now be monitored to determine if it meets the regulatory agency requirements before it is discharged into the public waterway. Two main parameters are continuously determined before the effluent is discharged. These are pH and total suspended solids. Sometimes, the temperature of the effluent is also determined depending on the temperature of the influent. At predetermined intervals, a complete analysis of effluent sample gathered by a continuous sampler (sample taken is proportional to effluent flow) is made as a control. These determinations, are mandatory and records must be kept for inspection by the regulatory agency.

Depending on the end use of the stream receiving the effluent, various criteria are set for the pH level, suspended solids, temperature and level of certain heavy inorganic ions which are toxic to aquatic life. For effluents discharged into streams used for public water supply and food processing, the effluent must meet the following:

a) Bacteria: Coliform group not to exceed 5,000 per 100 ml as a monthly average nor exceed this number by more than 20% of the samples examined during any month. Nor exceed 20,000 per 100 ml in more than 5% of such samples.

b) Threshold odor number: Not to exceed 24 (at 60°C) as a daily average.

c) Dissolved solids: Not to exceed 500 mg/1 as a monthly average nor exceed 750 mg/1 at any time.

d) Radioactive substance: Gross beta activity not to exceed 1,000 picocuries/1 nor 10 picocuries/1 for dissolve strontium -90 nor 3 picocuries for dissolved alpha emiters.

e) Heavy metals: Arsenic less than .05 mg/1, barium less than 1.0 mg/1, cadmium less than .01 mg/1, chromium (hexa) less than .05 mg/1, cyamide less than .025 mg/1, fluoride less than 1.0 mg/1, lead less than .05 mg/1, selenium less than .01 mg/1, silver less than .05 mg/1.

For industrial water supply, the dissolved solids level is slightly higher but the temperature is 95°F, pH is between 5 and 9 and dissolved oxygen is greater than 2 mg/1.

The design of a primary waste treatment system must therefore focus on the end goal and the treatment system developed must produce an effluent that meets this goal.

CHAPTER 2

WASTE CHARACTERIZATION AND DESIGN DATA GATHERING

In order to implement a pollution abatement program, be it in plant abatement or physical-chemical treatment, it is necessary to define the problem before setting up a plan of attack. Most industrial waste waters, are not clean enough for direct discharge into public waterways and means must be found to clean them.

The pollution problem, is generally recognized either by management or by a regulatory agency and the first and foremost step, is to define the waste water as completely as possible with respect to the degree of contamination, type and concentration of contaminats. This involves drawing the site and the sewer plan of the process facility to indentify all buildings, processes and sewer inlets and exists and points to sample and measure flows. In addition, the production methods in the plant, have to be evaluated to determine the effect of changing production rates and methods on the quality and quantity of waste waters generated. This plan prepares the grounds for gathering the necessary information for implementing an abatement scheme. The approach that follows, is oriented towards collection of data to provide a primary treatment facility since it has been assumed at the beginning of this thesis that management has decided to provide this treatment facility.

Sample Collection

Sample collection, is the logical step after defining the water pollution problem and setting up a plan to attack the problem. Sample collection and analysis is aimed at collecting the data necessary to characterize the various waste streams and to determine whether the characteristic of the waste can be altered and if the volume of the waste can be reduced by alteration of the process manufacturing methods.

A sample can be collected either by grab or composite sampling method. A grab sample is a single sample of the waste water stream where as a composite sample is one made from a series of samples collected over a period of time and then blended. Grab samples are useful in determining the effect of intermittent dumps but they do not provide reliable data on which to base the design of a treatment facility since they do not account for variations in waste flows and concentrations. On the other hand, composite samples, represent average conditions which typify what a treatment facility will handle.

Composite sampling is usually done by use of measuring devices which proportion the sample size to the flow rate. Manual composite sampling can also be done but it is expensive in that it requires a lot of manpower to do it. One type of automatic composite sampling system, consists of a flow sensor, a transmitter, a flow recording and sample proportioning controller, a continuous flow sample receiver and the sample bottle. See figure 1 below.

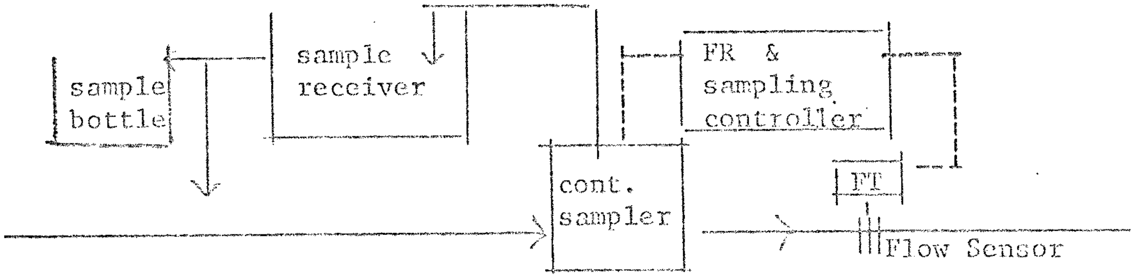


Figure 1. automatic composite sampling system

Other types of automatic composite sampling devices are programed to collect samples at intermittent time bases. There are a few problems with automatic composite sampling systems. These include, 1) power source to drive the pump since outfalls are usually remote from the process plant area, 2) line plugging due to suspended solids, 3) inability to collect a truely representative sample especially when the stream is stratified or suspended solid content is high, 4) inability to indicate extreme conditions. The solution to the third problem is to locate the sampler in areas where there is sufficient turbulence, expecially down stream of weirs or parshall fumes.

The samples collected, are taken to the laboratory for anaylsis on the average of about once or twice a shift depending on the available manpower and the changing nature of the waste. Sometimes, automatic composite sample collecting analysers are installed on stream which can simultaneously analyse multiple variables or one variable at a time, but these are generally too expensive to justify the savings in labor unless in a very complex process plant where the need to monitor several points automatically is important.

Other important considerations in setting up a sampling program, include the determination of the size of sample to be collected, types of analysis to be performed and proper sample handling and preservation. The size of the sample collected, depends on the number of laboratory tests to be performed. The analysis of the sample is generally specific and varies from one type of waste to another.

Sample Analysis

The objective here is to determine the concentrations of the individual contaminants and to establish effective treatment methods for reducing these contaminants. The regulatory agency, usually provides guidelines on the contaminants to be determined on the bases of the products of the process plant. However, it is highly recommended that a complete analysis be run at least in the initial stage to determine all constituent pollutants in the waste, because of ground infiltrations and leaching from sources external to the process plant boundry. A typical inital analysis will include the following parameters listed in Table 2.

Table 2. Sample Analysis Parameters

Parameter	Sample Preservation and storage time	Sample size (ml)
1. pH, colorimetric	No storage	15-20
2. Acidity or alkalinity	24 hours at $4^{o}C$	100
3. Total hardness	7 days at ambient conditions	50-100
4. Solids, total	7 days at 4^{o}	
dissolved, total	"	100-2000
fixed	"	
volatile	"	
5. Suspended, total	7 days at $4^{o}C$	50-1000
fixed	7 days at $4^{o}C$	
volatile	7 days at $4^{o}C$	
6. Settleable solids		500-1000
7. Nitrogen, total (as N)		
organic	7 days in 40 mg $H_gCl_2/1$ at $4^{o}C$	500-1000

free ammonia	7 days in 40 mg H_gCl_2/1 at 4^oC	500
nitrites	7 days in 40 mg H_gCl_2/1 at 4^oC	10-100
nitrates	7 days in 40 mg H_gCl_2/1 at 4^oC	10-100
8. Phosphorus, total (as P)		
organic	7 days in 40 mg H_gCl_2/1 at 4^oC	150-500
inorganic	" " " " " " " "	50-100
9. Anions		
Chlorides	7 days at ambient conditions	25-100
Sulfates	7 days at 4^oC	100-1000
Carbonates (CO 3)	7 days at 4^oC	100-200
Bicarbonates (HCO 3)	7 days at 4^oC	100-200
Cyanide	24 hours at pH 10	25-100
Flouride	7 days at ambient conditions	100-200
Sulfite	7 days in 2 ml Zn acetate/1	50-100
10. Cations		
Sodium	Filtrate 6 months in 3 ml 1:1 HNO_3/1	100-1000
Potassum	" " "	100-1000

Calcium	Filtrate 6 months in 3 ml 1:1 HNO_3/l	100-1000
Manganese	" " "	100-1000
Aluminum	" " "	100-1000
Copper	" " "	200-4000
Magnesium	" " "	100-1000
Nickel	" " "	100-1000
Lead	" " "	100-4000
Cadmium	" " "	100-1000
Mercury	" " "	100-1000
Arsenic	" " "	100-1000
Zinc	" " "	100-1000
Chromium (hexavalent)	" " "	100-1000
Chromium (total)	" " "	100-1000
Iron	" " "	100-1000
11. Oil and grease	24 days in 2 ml H_2SO_4/l at 4°C	3000-5000
12. Total organic carbon (TOC)	7 days in 2 ml H_2SO_4/l at 4°C	100-500
13. Biochemical oxygen demand (BOD)	6 hours at 4°C	100-500

14. Chemical oxygen demand (COD)	7 days in 2 ml H_2SO_4/1	50-100
15. Phenolic	24 hours in 1 gram $CUSO_4$/1 plus H_3PO_4 to pH 4 at 4°C	800-4000
16. Silica (SIO_2)		50-1000
17. Turbidity	7 days at ambient conditions	100-1000
18. Toxicity	----	1000-2000
19. Detergents	----	100-2000
20. Color	24 hours at 4°C	100-500
21. Odor	7 days at 4°C	100-500
22. Dissolved oxygen	No storage	500-1000

These parameters, are the most common industrial waste pollutants and the regulatory agency usually compiles its list from them, eliminating particular parameters which are not likely to be present in a given process waste. In special processes like nuclear plants, other parameters not listed above may be added to the list e.g. radioactive materials.

Specific tests and analytical methods to determine these parameters, are covered in standard and analytical textbooks. Such literature sources include:

1. Standard Methods for the Examination of Water and Waste Water, 13th Edition, American Public Health Assoc. 1971.
2. Methods for Chemical Analysis of Water Wastes, E.P.A. 16020-07/71, 1971.
3. AS & M Standards, Industrial Water: Atmospheric Analysis Part 23, October 1967.
4. Handbook for Analytical Quality Control in Water and Waste Water Laboratories, U.S. E.P.A. June 1972.

As a guideline for engineers who are designing a primary waste water treatment facility for the first time, a typical example on how to design laboratory tests for scale up, will be discussed. For this purpose, let us take a simple waste water from a sulfuric acid plant which has been sampled and analysed for all problem parameters and found to contain dissolved and suspended solids, turbidity, pH, total and dissolved iron in concentrations which exceed E.P.A. limits. A test program must now be set up to determine the treatability of this waste to meet E.P.A. limits. Table 3 below, shows influent characteristic and E.P.A. limits.

Parameter	Influent Characteristic	E.P.A.
suspended solids	45 mg/1	10 mg/1 (10 ppm)
dissolved solids	6000 mg/1	5000 mg/1
turbidity	21 JTU	1.5 JTU
pH	2.1 units	9 units
total iron	38.4 mg/1	2.5 mg/1
soluble iron	32 mg/1	1.7 mg/1
other heavy metal ions	less than 1 mg/1	less than 2 mg/1

Table 3. Problem Parameters and E.P.A. Limits

In order to conduct the laboratory test, a flow measuring device and automatic composite sampler, were installed in the combined outfalls discharging into the public waterways. A rectangular weir with standard end contractions was installed to measure the flow and an automatic composite sampler, the type described earlier, was installed to sample the stream. For the first day of normal production, the height of water over the weir was measured at intervals of one hour, for eight hours, using a ruler. The flow was caculated using the Francis Flow formulas for weirs.

$$Q\ (gpm) = 1495\ LH^{3/2}$$ where L = length of weir crest

H = head of water on weir

The average of the flows calculated for the eight heads of water on weir was used as the flow rate for that day. The measurements were made only during the day shift for two main reasons. One was the fact that waste water flow during normal production was fairly constant, the second reason was personnel safety since the measurement point was remote from the production area and it was considered unsafe for night readings. For the three feet weir crest used, a typical head was 0.5 feet.

$$Q\ (gpm) = 1495 \times 3 \times 0.5^{3/2}$$

$$= 4485 \times 0.35$$

$$= 1560$$

The calculated flows for a typical shift (gpm) were 1560, 1550, 1545, 1540, 1570, 1560, 1525, 1540. The average flow calculated to be 1550 gallons per minute.

Two thirty gallons composite samples were collected and sent to recommended equipment vendors to perform tests to establish retention time in the neutralizing tanks and the amount of neutralizing agent required, type of clarification and dewatering equipment best suited for the waste. In the meantime, tests were conducted in the plant laboratory to obtain similar data for cost estimates and economic evaluations.

Laboratory Tests

Determination of neutralizing agent required, retention time, overflow rate and sludge production rate.

Thirty gallons of a composite sample was neutralized in a 40 gallons PVC tank with agitation, using 50% caustic solution. The pH was measured by a pH electrode. The neutralization pH was varied between 7 and 11, using retention times varying from 10 to 30 minutes. Settling tests were conducted on the neutralized waste. The same test was conducted, using 10% lime solution. The results obtained using caustic will be used to illustrate the calculation of the design parameters.

The data for table 4 (sample neutralization and settling test result) is generated as follows. The 30 gallons sample is neutralized to a pH of 7 and the amount of 50% caustic solution consumed, is recorded. Agitation continues for a total of 10 minutes. Two samples are withdrawn for the determination of suspended solids and for settling rate test. About one liter of sample is required for suspended solids determination. This sample is filtered using regular laboratory filter paper. The cake is washed and dried to a constant weight in an oven at 110°C. The difference in weight between the empty filter paper and the filter paper with cake, is the weight of dry suspended solids.

$$\text{mg/l suspended solids} = \frac{A}{B} \times 1000$$

Table 4. Sample Neutralization and Settling Test Results

Sample Size Neutralized	Final pH	Ml of 50% NaOH Consumed	Suspended Solids in Raw Waste	Suspended Solids in Neutralized	Retention Time Minutes	Settling Test Result (Mg/l S.S in Sample) Sample Time Intervals, Minutes										
						h	10	20	30	40	50	60	70	80	90	100
30 Gals	7	Y	K	A	10	h_1										
						h_2										
						h_3										
						h_4										
						h_5										
				B	15	h_1										
						h_2										
						h_3										
						h_4										
						h_5										
				C	20	h_1										
						h_2										
						h_3										
						h_4										
						h_5										
				D	25	h_1										
						h_2										
						h_3										
						h_4										
						h_5										

Figure 2. Settling Tube Result

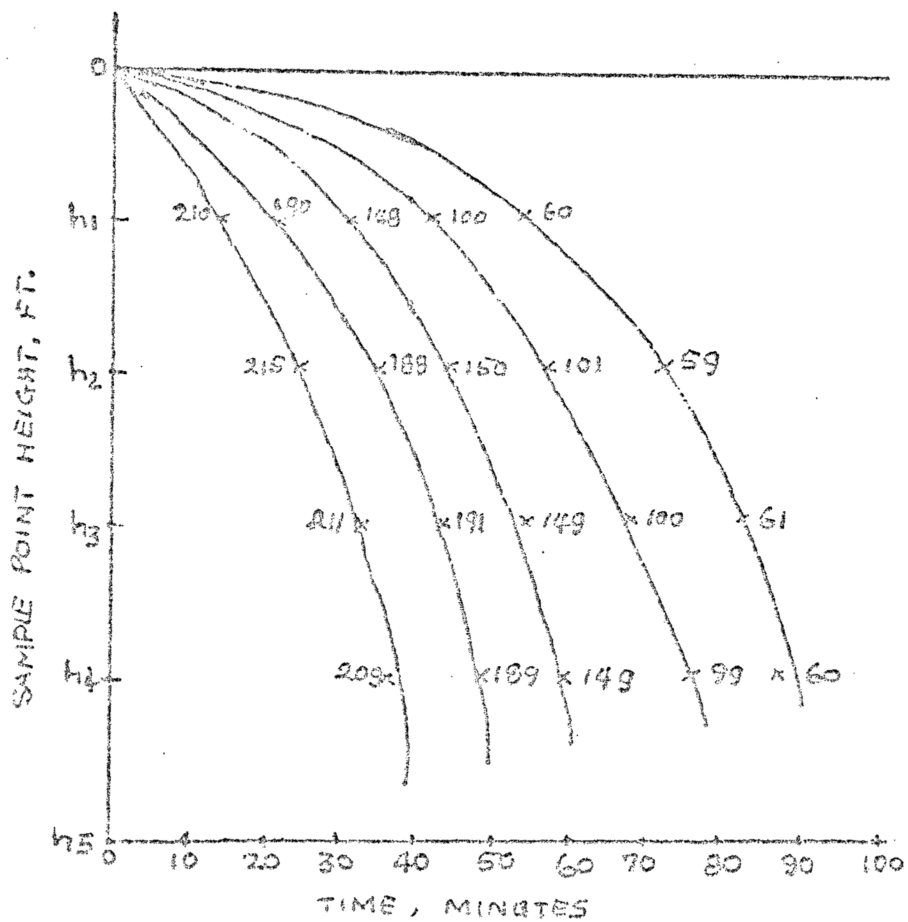
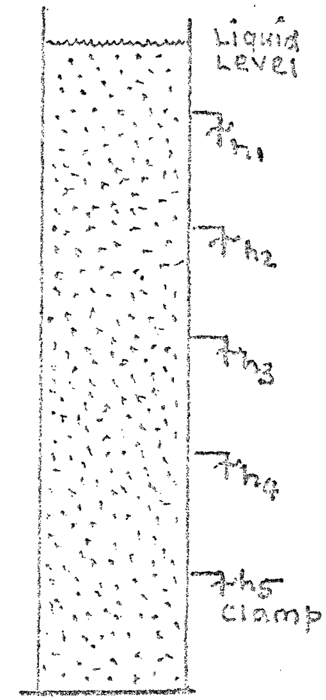


Figure 3. Settling Tube Lay Out



Where A = mg suspended solid

B = ml sample

About 15 gallons of the neutralized sample is required for settling test. A settling PVC tube, 10 feet in height (10 feet choosen to approximate normal depth of clarifiers) is used with sample ports spaced every two feet. Diameter of tube is 6", see the sektch, (Figure 3). At time intervals of 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 minutes, samples are withdrawn from these ports and analysed for suspended solids. The amount of suspended solids, is entered in Table 4. The curve shown in Figure 2 is then drawn. Figure 2 is obtained by plotting the suspended solids, mg/l against time and height (h_1 through h_5). All the points corresponding to the same amounts of suspended solids in the sample, are joined with a curve. The slope of the curve, gives the settling velocity, feet per minute.

Table 4 and Figure 2, are repeated for the various retention times and pH (7.5, 8, 8.5, 9, 9.5, 10, 10.5 and 11). The conditions which produce the curve with suspended solids at the level acceptable to the regulatory agency, establishes the conditions for the design of the treatment facility and the neutralizer, clarifier and dewatering equipments can be roughly sized to generate a cost estimate. More precise data, for final design, will be generated by the equipment vendors.

Approximate equipment sizes can be calculated from the laboratory data. Using results obtained at a pH of 9, we will illustrate the calculation.

a) <u>Neutralizing agent requirement:</u>

Let Y be the cc of 50% caustic solution required to bring the pH of 30 gallon waste from 2.1 to 9

50% NaOH = 500 gm/l

Therefore gm NaOH used = $\frac{Ycc}{1000 \ cc/l} \times 500 \frac{gm}{l} = Y/2$ gm

Total volume of waste to be handled per day, is

$1550 \frac{gal}{min} \times 1440 \frac{min}{day} = 2.24 \times 10^6$ galoons per day

Therefore daily consumption of caustic =

$2.24 \times 10^6 \frac{gal}{day} \times \frac{1}{30 \ gal} \times \frac{Y}{2}$ gm

$= .0376Y \times 10^6$ gm/day

= 8 2Y lb/day

b) <u>Retention time:</u>

In Figure 2, the test at pH 9 and retention time of 15 minutes, gave a curve for 10 mg/l in the sample. This indicates a retention time of 15 minutes, however, to play safe, use 20 minutes (note: Figure 2 shown is for pH 7).

c) <u>Overflow rate:</u>

To obtain this parameter, a tangent is drawn at the point of 10 mg/l on the curve. The slope is the settling velocity, foot per minute. Overflow rate equals slope (ft/min.) x 7.48 gal/ft^3. However, it is usual to express overflow rate (surface loading) in gallons per day per square foot. Therefore surface loading

$$= \text{slope ft/min} \times 7.48 \frac{\text{gal}}{\text{ft}^3} \times 1440 \frac{\text{min.}}{\text{day}}$$

d) Sludge volume:

The natant liquid in the PVC test tube is siphoned and the bottom transfered to a graduated cylinder. Let Zcc be the volume of sludge.

$$\text{Volume of PVC test tube} = (0.5)^2 \times .785 \times 10$$

$$= 1.97 \text{ ft}^3$$

$$= 14.7 \text{ gallons}$$

Therefore gallons per day sludge

$$= \text{Zcc} \times \frac{1}{3{,}700 \text{ cc/gal}} \times \frac{2.24}{14.7 \text{ gal}} \times 10^6 \text{ gal/day}$$

$$= 41\text{Z gallons per day}$$

Items a through d with the established waste flow, provide a fairly good basis for initial process design and a cost estimate for economic analysis.

There are many variations in the laboratory test methods used to establish settling velocities and overflow rates of the clarifiers in addition to the one described. One of these, is interface measurement in a long transparent tube like a laboratory graduated cylinder. In this method, the interface height is measured with time until the height is fairly constant. The difference between initial and final interface heights divided by total time in minutes give the settling rate in cc/minute, which can then be converted into surface loading in gallons per day per square foot.

A final remark is the design of laboratory test to incorporate projected waste characteristics some ten to fifteen years later. This is often necessary because of process plant expansion. This is basically done by producing synthetic wastes composed of the mixture of the present waste sample and various proportions of added polluting components. The proportion added is determined by a projection of what the waste would be when production rates go up or new products are manufactured. This synthetic waste is then analysed as described previously. The results will give an indication of how much flexibility should be built into the proposed waste treatment facility to ensure its capacity to handle the wastes produced ten to fifteen years later.

CHAPTER 3

EVALUATION OF DATA AGAINST EPA REQUIREMENTS

The idea behind the laboratory tests discussed earlier, is to demonstrate the treatability of the industrial waste waters generated in the process plant. The analytical results must now be put in a report form to be presented to the management and subsequently to the regulatory agency. As has become the practice since the late sixties, most medium and large size companies, have their environmental protection divisions which coordinate the pollution abatement efforts of their company with the regulatory agency. The need for this separate division has progressively become important as the federal and state environmental protection requirements have grown stricter each time.

The management reviews the analytical results to determine 1), whether the waste waters can be treated to provide effluent that meets the regulatory agency criteria for discharge and 2), the economic impact of the new treatment facility on the overall operating cost of the process plant. Therefore, while demonstrating that the waste waters can be treated to produce an effluent acceptable to the regulatory agency, the associated cost of the treatment facility must be such that the process plant to be supported can still operate profitably. The section under Cost Estimate (Chapter 4) will contain the parameters for economic analysis and here, it is pointed out only as one of the important factors which influence the decision to provide the treatment facility.

The regulatory agency on the other hand, reviews the report to determine if it meets the established criteria and whether the analytical test methods are valid with respect to standard analytical methods. In addition to the analytical test methods and results, a brief description of the proposed abatement scheme and dates to complete the scheme, must also be provided. This will give the regulatory agency an overall picture of the abatement program.

A typical report to the regulatory agency must therefore contain as a minimum the following:

a) A brief description of the sample collection method.
b) A short description of the analytical method.
c) A table showing the influent characteristics, possible level of reduction and the corresponding regulatory agency set criteria.
d) A summary of the proposed abatement scheme.
d) The schedule for completion of the abatement scheme.

In general, test results which indicate the abatement scheme will produce effluent quality better or equal to that established by the regulatory agency, requires a minimum of effort from the manufacturer to make the results acceptable to the regulatory agency. In this case, it will be relatively easy to obtain a discharge permit from the regulatory agency. On the other hand, if the test results indicate the effluent cannot meet the quality established by the regulatory agency, real bargaining at much higher levels will be required, because it involves major economic decisions which may lead to process plant shutdown and loss of jobs and revenues.

Parameters Which Deviate From EPA Criteria

Quite often, laboratory tests do not produce conclusive evidence that a proposed abatement scheme will produce an effluent which consistently meets the criteria set forth by the regulatory agency. This failure to meet set requirements, may be due to improper sampling and test methods or may be a result of a real problem with treateability of the waste and in which case a different kind of solution to the problem is required.

The general approach to this kind of problem, is a re-examination of all test methods to eliminate the probable errors due to improper test procedures and where necessary, to hire the services of a good consultant. The usual practice in the industry and for good reasons too, is to employ the services of an outside consultant. This is more practical and reliable because waste characterization is a tedious task which requires professional talents in addition to a crew of technical aids. This creates a burden on the operating process staff since the pollution abatement crew must contain professionals who are familiar with the process plant and must therefore come from the plant staff. Secondly, waste characterization is a fairly new field and although the technology for this purpose does exist, the parameters to be determined are so variable that the expertise needed for a quantitative and qualitative analysis of the waste can sometimes be provided only be an outside specialized group.

The need to establish that test results truly represent the characteristic nature of the waste and what to be expected of it in a treatment facility, cannot be over emphasized. This is because effluent discharge permits are written around very tight limits and violation of these limits carry penalties of fine, imprisonment and law suits depending on the frequency of violation and the nature of the violation. Therefore where laboratory tests fail to establish a suscesful abatement scheme, the regulatory agency should be kept informed to allow time for another approach to the problem.

The only other alternate is in-plant abatement. An in-plant abatement program is a lot more complex than an end of pipe treatment but at the same time, it has the potential for savings by the improvement of equipment operating efficiencies and by product recoveries. An in-plant abatement scheme, should generally be considered because in addition to the above advantages, a successful in-plant abatement program will usually reduce the waste volume and concentration of pollutants to be treated in an end of pipe treatment facility, thus treatment costs are reduced.

An in-plant abatement scheme, is abatement at the source and although it has long been practical in the industry, it was used only as a means to improve the return on investment by the recovery of by products and more efficient operation of process equipments; but today, it is becoming important in all abatement programs in anticipation of the Federal Water Pollution Control Act Amendments of 1972 which among other requirements, aims at zero discharge by the year 1985. A source abatement program, involves a study of an individual process operation aimed at material and heat balances (feeds, products, losses and stream temperatures) around the process unit, monitoring the waste generated for flows and concentrations of pollutants and modification of equipments and or operating methods to reduce and or eliminate waste volumes and level of contaminations. To this must be added a review of the entire plant material handling procedures to minimize spills. These are general guidelines and specific steps taken in each case will depend on the particular process units involved.

The cost savings of a source abatement program can be quantified on the basis of comparism between the cost of a proposed waste treatment facility expressed in dollars per gallon (and dollars per pound of a major pollutant in the waste) and the cost of source abatement changes and savings in waste volume and contaminant level reductions. For example, suppose a proposed primary waste treatment facility to treat 1550 gallons per minute of waste (2.23×10^6 gallons per day) containing 45 mg/liter suspended solids (103.5 pound dry solids) requires a capital investment of $5.4 million (excluding taxes, interest rate, depreciation, operating cost and maintenance). On a daily basis, this is equivalent to $2.36/gallon/day (or $50,000/pound dry solids). The capital cost of a source abatement program can now be compared on the bases of the reduction in flow and volume of sludge to be handled.

<u>Waste Treatment Cost and Marginal Processes</u>

Decisions to provide waste treatment facilities are economic and should be treated as such. Available technology today for cleaning polluted waters have been oriented mainly to produce an effluent which meets the regulatory agency standard with little consideration for ways of earning a return on investment. Besides source abatement methods which have been demonstrated to generate savings and improve profit margin of the process plant, conscientious effort should be made to reuse the effluent in the process plant. This becomes more important for marginal processes where every penny saved justifies the continued existence of the plant.

In liquid handling process plants, investments on utilities, range from 10 to 20% of the capital investments. These include water distribution system, cooling towers, boilers, water conditioning facilities and sometime, power generation systems. Raw water costs about $.03 per thousand gallons and treated water for various other uses in the plant, could run up to $.2 per thousand gallons for boiler feed water. By an in-plant water conservation methods, losses in blow down, venting, leaks and dumping can be reduced. This reduction combined with the reuse of treated effluent in selected non-critical process application would greatly reduce the water changes for a typical process plant and thus improve the profit margin of the whole operation.

The penalty for not taking these measures, will be a shutdown of a marginal manufacturing facility with losses in jobs, tax revenues for governments (local, state and federal) and loss of the market for the discontinued products. The image of the manufacturer could also be tarnished unless proper steps are taken to replace the discontinued products from other manufacturing facility.

CHAPTER 4

COST ESTIMATE

The studies and tests discussed in chapter 2 which dealt with "Waste Characterization and Design Data Gathering" provide sufficient information to develop a process flow sheet, waste segregation and collection, thus providing the elements for generating a cost estimate for budget planning and economic evaluation. This cost estimate however, is preliminary and requires refinement when equipment vendors perform sample tests on the waste to select the equipment.

The cost estimate can be based on telephone inquires from equipment vendors, published cost indices from literature sources or by applying the 6/10th rule to a similar treatment facility of a different size which has been built. For idential treatment facilities where size difference is less than 10 fold, the 6/10 rule applied to the main components of the vacility, provides a fairly good estimate provided cost escalation factors are accounted for in the calculations. For the quality of estimate desired at this stage of process development, the estimate generated by telephone inquiring, should be compared with that obtained by applying the 6/10th rule to the major components of the treatment facility with addition of escalation factors.

As an example, consider the waste characterized in Chapter 2, is to be treated and we therefore have to estimate the cost of providing the treatment facility. Let us suppose further that we have the cost of a similar facility installed two years ago to treat 1.44×10^6 gallons per day (1000 gpm). In applying the 6/10th factor to the major components, let the suffix 1 represent a component in the previous job and suffix 2 that desired for the new job. The new job like the old one, requires two equalization basins, three neutralizers, two clarifers and two vacuum filters and the sizes of these established on the basis of the study and tests in Chapter 2. The volume of waste is 2.23×10^6 gallons per day (1550 gpm).

<u>Cost Calculation</u>

1. Cost of equipment purchased

$$C_2 = C_1 \left(\frac{V2}{V1}\right)^{.6}$$

$$= 400 \times 10^3 \left(\frac{1550}{1000}\right)^{.6}$$

$$= .4 \times 10^6 \times (1.55)^{.6}$$

$$= .4 \times 10^6 \times 1.274$$

$$C_2 = \$510,000$$

2. Equipment installation

$$C_2 = 110,000 \times 1.274$$

$$C_2 = \$140,000$$

3. Instruments and controls

$$C_2 = 130,000 \times 1.274$$

$$C_2 = \$165,000$$

4. Piping including sewers and equalization basins

$$C_2 = 1.2 \times 10^6 \times 1.274$$

$C_2 = \$1.55 \times 10^6$

5. Electrical

$C_2 = 125{,}000 \times 1.274$

$C_2 = \$160{,}000$

6. Building and accessories

$C_2 = 230{,}000 \times 1.274$

$C_2 = \$292{,}000$

7. Site improvement

$C_2 = 75{,}000 \times 1.274$

$C_2 = \$95{,}000$

8. Utilities and miscellaneous

$C_2 = 180{,}000 \times 1.274$

$C_2 = \$230{,}000$

9. Total capital cost

	New Plant	Old Plant
	\$ x 1000	\$ x 1000
	510	400
	140	110
	165	130
	1550	1200
	160	125
	292	230
	95	75
	230	180
Total	$\$3.142 \times 10^6$	$\$2.450 \times 10^6$

10. Total cost of old job, capital and expense was \$(2.450 x 10^6 plus .990 x 10^6 = \$3.440 x 10^6.

Therefore total cost of new job, capital and expense is

$$\frac{2.45 \times 10^6}{3.44 \times 10^6} = \frac{3.142 \times 106}{X} \quad \text{Therefore } X = \$4.45 \times 10^6$$

Where X = total capital and expense cost of the new job.

11. The cost escalation factor from technical magazine sources, is 10%. Therefore total cost of the new facility, capital and expense is:

$$\begin{array}{r} .445 \times 10^6 \\ \underline{\$4.45 \times 10^6} \\ \$4.895 \times 10^6 \end{array}$$

Where time permits, this final total cost should be confirmed with telephone inquiring from vendors and contractors.

Impact On Operating Cost of Process Plant

The total capital and expense cost of the new vacility established above, is used as the primary input for economic analysis designed to establish the profit margin of the existing process plant which this new facility will support. The details of this analysis are too complex to be covered here but it is useful to add that the factors considered in such analysis include the following:

a) Cost of the borrowed capital for the new plant

b) Insurance

c) Taxes

d) Depreciation

e) Maintenance and operating cost

f) The cost of continued process plant operation

g) Unit price of manufactured product

h) Market research to determine the probability of selling the manufactured product at the new higher cost.

Cost Estimate Package

The cost estimate package is a document which briefly describes the facility being provided and the associated cost for providing it. The degree of accuracy of this document, is very important because it provides elements on which economic decisions are to be taken. An erroneous estimate, leads to false conclusions with very serious future economic consequencies. For a waste treatment facility where return on invenstment cannot be measured directly, an inflated estimate leads to close down of the process plant and loss of jobs, and profits. A low estimate on the other hand, gives a false impression of financial soundness and for marginal process plants, the future effects are process plant shut down with outstanding debts to be paid. Therefore, every effort should be made to produce an estimate as goods as the in-put data.

The estimate package should contain the following information:

1) General description of what the treatment facility will achieve in terms of cleaning the effluent.

2) Proposed location of the facility.

3) Raw materials, utility, storage and disposal requirements.

4) Brief process description which covers the stages of the treatment from waste water collection to effluent and sludge disposal.

5) Proposed design basis on which cost estimate is generated. This should include waste water characterization, and effluent quality.

6) The cost estimate summary, items 1 through 11 under cost calculation with explanation of the suffixes 1 and 2.

7) The drawings prepared for the estimate.

8) Proposed engineering method - in house versus contract and the type of construction contract.

9) A summary of the components included in the cost estimate: a), equipment list and approximate sizes, b), equipment installation, foundations, pipe racks etc, c), list of instruments and controls, d) piping, types, materials and quantities, sewer network, waste segregation and equalization basins, e), estimated KVA power required and at what voltages, f), number of buildings required, their use and type of equipments, fixtures and furniture to be provided, g), site improvement, grading, roads, fences, drainage etc, h), utilities and miscellaneous should include steam, potable water, plant and instrument air, cooling water, refrigeration and air-conditioning requirements, i), estimated engineering and drafting manhours and a tentative schedule for project completion and start-up.

The validity or degree of accuracy of the cost estimate is always in question since important economic decisions which involve commitment of large sums of money and manpower are based on the cost estimate. Therefore, additional information must be furnished with the estimate to allow for risk analysis which narrows down the degree of uncertainty by establishing levels of confidence and the degree of risk involved in the project. For the preliminary cost estimate generated for the proposed primary waste treatment facility, a risk analysis will involve the estimators judgement as to what the lower and upper limits of the individual cost items are with justification as to sources used in establishing the limits, refer to Table 5.

Column one is the cost of the item expressed as percentage of the total cost. Column two is the expected cost of the item as previously calculated with a 10% escalation factor. Column three is the lower and upper limits established by the estimator. Column four is the product of columns one and three divided by 100. The totals on column four, indicate that the true value of the cost estimate, lies somewhere between - 13.23% and + 8.54% of the total shown in column two, that is, between $\$4.345 \times 10^6$ and $\$5,315 \times 10^6$. This corresponds to a spread of about one million dollars on an estimate which is under five million dollars. Therefore, further analysis is required to narrow down the degree of uncertainty. To do this, the client must define how much risk of overrun he is prepared to take. Assuming this is 10%, that is, the client desires a 90% degree of certainty the actual cost will not be greater than the cost estimate. Figure 4 is drawn by using as the coordinate the computed under/over estimated values (-13.23, 90%)

and (+8.54, 10%). The 10% risk of overrun, is the maximum applicable contingency to the estimate to ensure a 90% level of confidence. We therefore apply a 10% contingency to the estimate resulting in a total estimated cost of the primary treatment facility of $\$4.895 \times 10^6$ plus $\$.489 \times 10^6$, or $\$5.3845 \times 10^6$.

Figure 4. Contingenty Chart

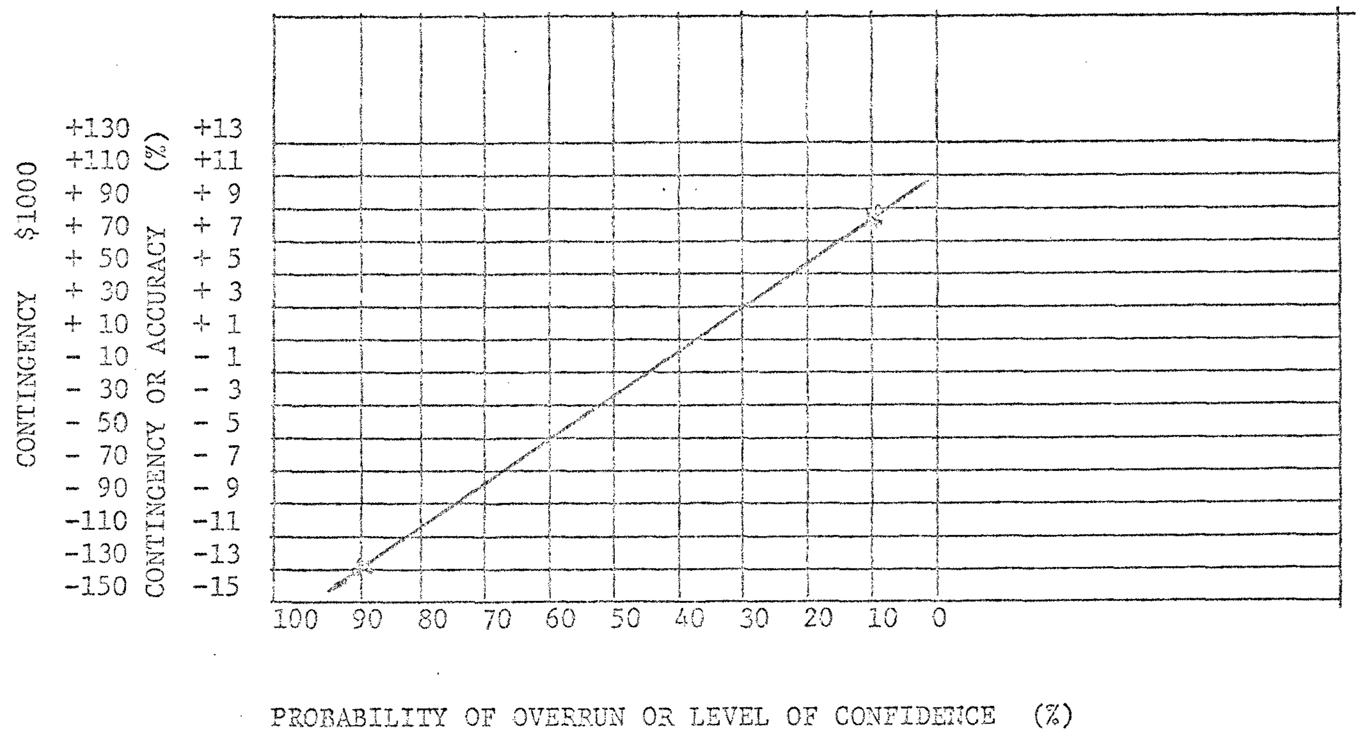


Table 5 Cost Estimate Single Sheet Summary

Item	% of Total	Cost $\$ \times 10^3$	% Variance From Est. Cost.		Wgt. % from Estimated Cost	
			-	+	-	+
1. Equipment purchased	11.44	561	5	3	.57	.34
2. Equipment installed	3.15	154	10	5	.32	.16
3. Instruments & cont.	3.72	181.5	2	2	.07	.07
4. Piping & basins	34.80	1705	20	15	6.94	5.70
5. Electrical	3.59	176	1	2	.04	.08
6. Building & Acces.	6.56	321.2	4	2	.26	.13
7. Site improvement	2.14	104.5	6	4	.13	.09
8. Utilities & Misc.	5.18	253	10	10	.50	.50
9. Expense	29.42	1438.8	15	5	4.40	1.47
10. Total	100	4895			13.23	8.54

CHAPTER 5

PLANNING, SCHEDULING AND CONTROL

Project planning and scheduling, are tools commonly employed to control the orderly and chronological progress of a project from start to finish. In definite terms, project planning provides a means for determining the demand for available resources of men, materials, machines, money and the order of commitment of these resources in separate but related activities to achieve a predetermined goal. On the other hand, project scheduling, is the actual commitment of these resources at definite time periods according to requirements of the project and within the limits of available resources.

The most important features of project planning are the identification of tasks to be performed and the goals to be attained. Once this is accomplished, the next logical step is to transforme this into a working schedule. For proper project execution, every phase of the project should have a separate schedule of its own. Only in this way can the activities associated with every phase can be taken into account. For the waste treatment facility that is being proposed illustratively in this thesis, typical project phase requiring separate schedules would be the following:

a) Waste water characterization program

b) Summary of test results

c) Test result evaluation

d) Environmental Protection Agency test result submittal, review and approval.

e) Preliminary process design

f) Cost estimate and approval package

g) Client approval and funds authorization

h) Final process design

i) Mechanical process design

j) Equipment requisition, bid analysis and purchase orders

k) Equipment delivery and vendor prints schedule

l) Soil borings and civil design

m) Contract bids, bids analysis and bids award

n) Construction schedule

o) Schedule for cost reporting, progress reviews, etc.

p) Electrical design and instrument selection

Figures 5 and 6, show a typical planning schedule for the overall project and for the mechanical design phase of the project in the simplest form. The relationship between the activities, level of manpower commitment and definite start and finish dates are generally more clearly shown in the planning technique commonly referred to as "Critical Path Method (CPM) or Program Evaluation and Review Technique (PERT)". The advantages of this technique are that it provides at a glance:

1. The start and finish dates for each activity

2. A definite relationship between the activities and the sequence for performing them to ensure that succeeding activities

can be started within their early and late start dates.

3. The level of manpower at which an activity must be manned to complete it within the planned duration.

4. The critical path of the project and the total time required to complete the project.

However, CPM planning technique is very elaborate because it breaks every task into small controllable activities and therefore often requires a planning engineer on a full time bases. With the advances of computer sciences, planning and scheduling are often performed with the digital computer especially for medium to large size projects ($5 million or more) where more than 200 activities are involved.

For the sake of completeness, mention must also be made of the oldest planning and scheduling technique which is commonly used at the initial stages of planning of most projects. This is the BAR or GANTT chart. It is a very simple planning technique and is quite useful for most simple projects. This technique involves representation of the activities on the ordinate and time duration on the abscissa. The length of the bar, shows the duration of the activity, the beginning and ending of the bar, shows the approximate start and finish dates of the activity.

Project Control

A. Cost Report and Control

Proper project control requires a means to monitor the activities of the project and to apply adequate controls when necessary. The means available for doing this, are cost and progress reports since the former determines whether the project is progressing within cost and the latter whether the project will be completed within the planned period.

Cost reporting in a capital project, deals with the periodic accounting for funds already spent or committed to be spent and extrapolating to predict how much is required to complete the project. This information is then compared with the original budget/control estimate to determine deviations from the budget estimate. Cost control is the analysis of the cost report and the application of appropriate measures to correct deviations from the control point and thus ensure project completion under or at budget cost.

For medium to large size capital projects where many cost components are involved, cost reporting and control, turn out to be a major job requiring special techniques to facilitate those chores which have to be done every two weeks to once a month, depending on the level of activity. A proper organization or grouping of items and a good format is of paramount importance because it not only facilitates the chore of reporting but also makes it easier for the various supervisors and design engineers to understand and this facilitates the control efforts. In a typical engineering setup where several projects are handled, the need for up-to-date information for preparing cost estimates, is very important, and the most common cost reporting format is that which breaks down the project components into various categories with a code number usually referred to as a "code of accounts". This code number, identifies the piece of equipment or activity whose cost must be reported and controlled if necessary. Certain basic elements are essential for effective cost reporting and control. Of primary importance is timeliness. Presentation of cost reports several weeks apart, may result in an ineffective cost control because trouble items, which cost more than budgeted, may have progressed too far to be effectively corrected at minimum cost and inconvenience to those involved. The complexity or scope of a project is not good enough an excuse to delay the cost report. In fact, in such cases, sufficient justification exists for the use of data processing techniques. As applied to cost reporting, data processing is relatively straight forward, involving major effort only initially when the basic cost elements of the project are punched onto cards. For subsequent reports, only new data need be fed into the computer to obtain a complete cost report print out in any designated format. The advantages of using the computor for cost reporting are basically the same as in the application of computers in other engineering activities which are repetitive in that, the report is consistent and correct. The computer has no soul nor can it think and therefore, it cannot forget nor does it become demoralized by the boredom of repetitiousness.

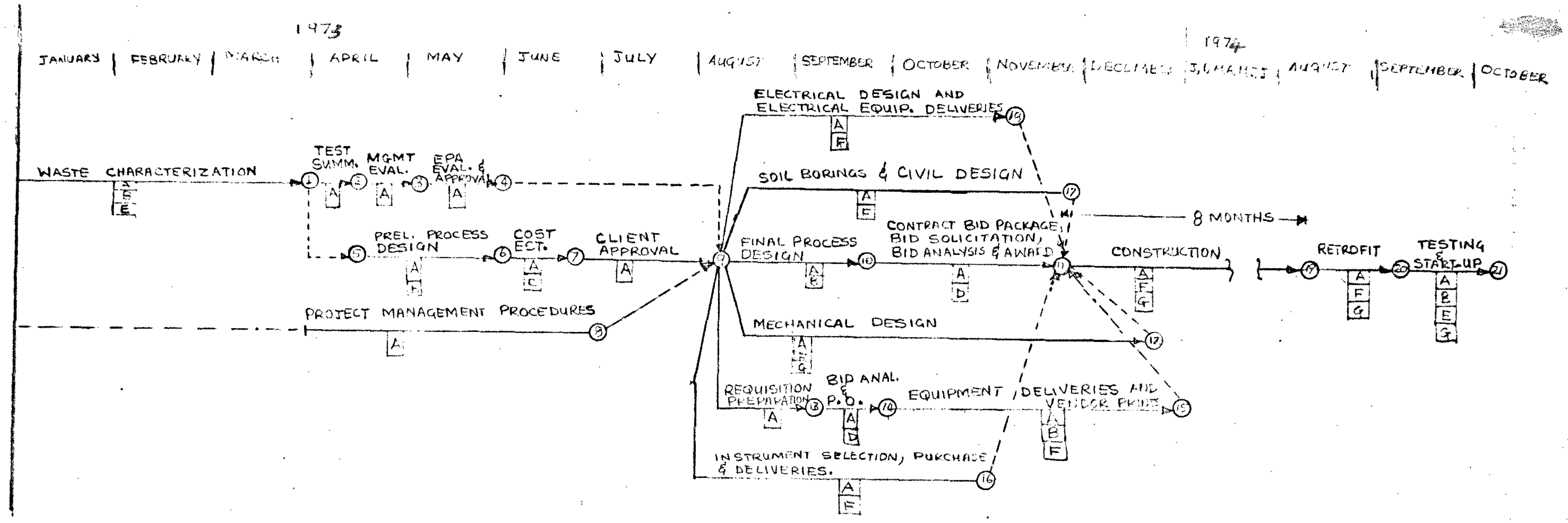
The investment in manpower and or machinery to produce timely and accurate cost report, is useless if the information generated in the cost report is not used for the purpose for which it is produced. In fact, like cost reporting, cost control is a continuous project activity and is time dependent. Any delay in applying corrective measure to a project cost element undergoing deviation from the budgeted cost, further increases the cost of making such correction as well as makes the correction more difficult to achieve. Therefore, the project engineer has to be on top of the project, watching for troublesome cost elements, applying adequate corrective measures, be it in increased manpower expenditure or delayed schedule, to ensure the completion of the project under or at budget cost.

Some of these corrective measures and the subsequent monitoring to ensure they are complied with may be unpleasant to some of the people involved especially when no attempt has been made to explain why the measures are necessary. It is therefore good engineering management to keep every body informed of these measures and why they are necessary.

B. Progress Report and Control

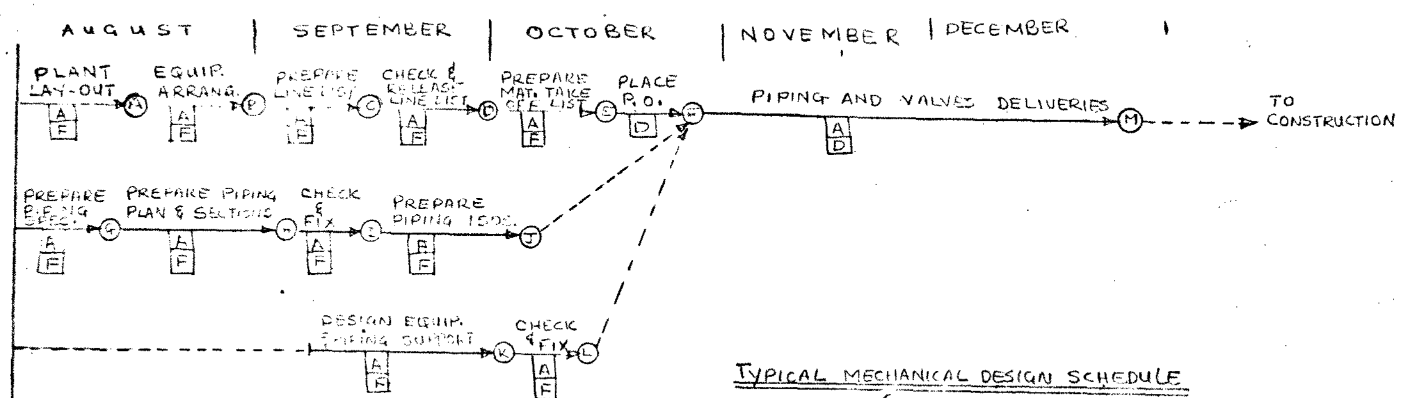
Progress reporting is a barometer for determining how well a project is progressing, time and money wise. This determination is necessary because only very few projects proceed exactly as originally planned and therefore, there is always the need to modify a project schedule to effect changes brought on during the progress of the project. Progress and status reports therefore, provide a verification of the project schedule or more appropriately, provide an index for determining the level to man the project. If the progress report indicates that the project is on schedule, the project engineer does not necessarily have cause to rejoice because the report is a synthesis of inputs from various design groups and more often than not, there is always a tendency to make things look better than they really are. The project engineer's best bet is to maintain his vigilance and back check the input for the progress report on a one by one basis. On the other hand if the progress report indicates that the project is behind schedule, as is often the case, the project engineer must find out whether the lag behind schedule is due to lack of information, or lack of action by him or any member of the design group or ultimately lack of sufficient manpower. Once he is able to determine the cause of the delay in schedule, a corrective action becomes a matter of routine. For causes beyond his immediate control, like manpower limitation, he can always have his management support his decision and provide the additional manpower required to effectively complete the project, as long as he can substantiate this shortage.

The progress report, unlike cost reporting, is usually issued on a monthly basis, the reasoning behind this long interval being mainly the fact that activities take time to cross definite "milestones" or convenient break points. A typical monthly progress report, will list current manpower against scheduled manpower in each design group, manhours spent in the current month in each design group, and the total manhours spent to date for each group and a forecaste of the manhours required by each group to complete the project. In-direct manhours like secretarial help, consultants, and management time, must be reported if these were included in the original schedule. Progress reporting using percentage completed, should be used with extreme care since quite often they are misleading. For example, a statement like "civil work" is 40% complete does not really lend itself to clear understanding. Does this mean that the civil group has spent 40 men weeks of the 100 men weeks estimated or that the amount of civil work done is the equivalent of 40% for such type of civil work. A little care in itemizing the units of work and the amount of work done in each unit, lends itself to a clearer understanding and at the same time, forces the data collecting individual to take a closer look at the overall work requirement for that group.



OVERALL PROJECT PLANNING SCHEDULE

TABLE 5



TYPICAL MECHANICAL DESIGN SCHEDULE

TABLE 6

LEGEND

A = ENGINEER OR MANAGER
B = CHEMIST
C = COST ENGINEER
D = PURCHASING AGENT
E = TECHNICIAN
F = DESIGNER
G = MECHANIC (P/F, ELECTR., WELDER)

CHAPTER 6

PROCESS DESIGN

Process design deals with the transformation of process information into a working flow sheet which forms the basis of all future design. The process flow sheet establishes the material and heat flows in the process, and the piping and instrument diagram established the instrument, equipment, and pipe sizes required and therefore they form the basis for plant cost estimate which is the primary reference document for economic planning and budgeting.

At this point, it is essential to look at the stages which lead to the development of the flow sheet. These include a) process definition as to its objective, b) design data on which all design must be based, c) general design philosophy, and equipment and instrument preferences, d) any unusual requirements of the proposed process. This information is usually furnished by the client at the initial stage of the process. However, it is not always possible for the client to cover all the items before his initial submittal of design information, and therefore the design usually commences with incomplete information. This makes it necessary to maintain communication with the client to establish further design information gathering. In some cases, the initial design information has to be revised due to changes in market conditions with respect to quality or quantity of product, or changes due to better data gathering technique or even a new process development.

In order to ensure a firm basis of design, the design engineer must usually generate a check list for evaluation of the design data transmitted by the client. For the primary waste treatment facility that this thesis is using as an illustrative example, such a list must include the following:

a) Plant location

b) Characteristic of the waste to be cleaned

c) Effluent quality desired

d) Laboratory assays to demonstrate the attainment of the effluent quality

e) Volume of waste to be treated

f) EPA time table with respect to when the treatment facility must start operation

g) Raw materials requirements -

  i) Neutralizing agent, type and quantity

  ii) Coagulating agent, type and quantity

  iii) If vacuum filtration required, type and quantity of pre-coat to be used

  iv) Storage requirements for the raw materials

h) Sludge disposal requirements -

  i) Trucking to a dump land site

  ii) Ocean disposal

  iii) Incineration

i) Volume of sludge produced per day and its composition and pre-centage weight (dry basis)

j) Utilities requirements -

i) Stream, low pressure

ii) Water: potable and process

iii) Air: instrument and plant

iv) Refrigeration, laboratory

v) Air conditioning, building

vi) Electricity 110/220, 220/440 volts

k) Client operating philosophy and equipment sparing

l) Client preferences for equipment and instruments

m) Any unusual requirements for operating the facility

This check list serves as a guide for this type of process work and it could be expanded further depending on individual needs.

It is appropriate at this point to emphasize that although the client has the responsibility to supply this information, he often does not have all the expertise needed to generate all the information and in many cases a preliminary process design is required.

Process Design Calculations

A. Material balance: See process flow sheet (Figure 7)

i) Stream (5) = streams (3) + (4) + (13)

$$(3) = 1550 \text{ gallons/min} \times 60 \frac{\text{min}}{\text{hour}} \times 8.3 \frac{\text{lb}}{\text{gal.}} \text{ (sp.gr. = 1)}$$

$$= 770{,}000 \text{ lb/hr}$$

(4) = Zero at normal operating condition

$$(13) = \frac{82Y \text{ lb/day}}{24 \text{ hr/day}}$$ (82Y lb/day established in Chapter 2)

(13) = 3.42Y lb/hr.

For the waste involved, Y varies from 80 to 110. If Y = 100,

(13) = 342 lb/hr.

ii) Stream (1) = (2) = (3)

iii) Stream (7) = sludge feed to vacuum filters

= 41Z gallon/day (established in Chapter 2)

$$= \frac{41Z \text{ gal/day}}{24 \text{ hr/day}} \times 1.15 \times 8.3 \text{ lb/gal}$$ (sp.gr = 1.15)

= 16.3Z lb/hr.

For the waste involved, Z is in the order of magnitude of 1000

Therefore, (7) = 16,300 lb/hr

iv) Stream (6) = the overflow from vacuum filter

= zero for this calculation

v) Stream (8) = filtrate

Vacuum filters produce cake as dry as 40%. Let us use 35% by weight solids for this calculation. Suppose the test in Chapter 2 showed a solid concentration of 10,000 mg/l, that is 1% solids by weight.

Therefore solid (dry basis) $= 16{,}300 \times \frac{1}{100}$ lb/hr

= 163 lb/hr

Therefore, weight of cake without precoat $= \frac{100}{35} \times 163$

= 465 lb/hr

Therefore, stream (8) = 16,300 - 465

= 15,835

Stream (9) = (8) with one vacuum filter in operation

vi) Stream (10) = (5) + (15) - (16)

For this kind of waste, stream (15) which is the polyelectolyte feed, varies from .04 to .06mg/1. Using .05mg/1, that is, 1185mg/gal. Therefore, ploymer usage per hour is

$$1550 \frac{\text{gal.}}{\text{min.}} \times 60 \frac{\text{min.}}{\text{hr.}} \times \frac{185\text{mg}}{\text{gal}} \times \frac{1}{454 \text{ ga/lb}} \times \frac{1}{1000\text{mg/gm}}$$

= .04lb/hr approx. negligible

Therefore, (10) = (5) - (16)

= 770,342 - 465

(10) = 769,877

vii) Stream (11) is zero at normal operating conditions

viii) Stream (12) = precoat consumption

For this kind of waste, precoat consumption is in the range of .012 to .015lb/gal. Using .014lb/9.5lb sludge

Therefore, precoat used = $\frac{.014}{9.5} \times 16,300 \frac{\text{lb}}{\text{hr.}}$

(12)= 24lb/hr.

ix) Stream (14) = steam required to keep caustic solution at 60°F in the winter = 12,000 lb/hr.

x) Stream (16) = (7) - (9) + (12)

= 16,300 - 15,835 = 24

= 489lb/hr

B. Equipment Sizing

i) Lift station: There is no real criteria for sizing the lift station. The only important consideration is the size of the deep well pumps to be installed. Therefore, we can arbitrarily select a well 25 feet by 20 feet by 15 feet deep, with the well being acid brick lined.

ii) The equalization basins: They will be sized to hold waste water generated in 48 hours. That is, 24 hours holding capacity for each of the two basins (2.23×10^6 gallons each based on 1550 gallons per minute of material to be processed). A basin 150 feet by 250 feet by 10 feet deep will be adequate. The basins will be rubber lined to prevent ground water pollution.

iii) Neutralizers: For reasons given in Chapter 1, and established retention time of 20 minutes (Chapter 2), a total of three units will be used, each having a capacity of 1550 gallon/minutes x 20 minutes x 1/3 equals 10,300 gallons. To prevent spills during agitation, a 12,000 gallons capacity unit is selected. A 12 feet diameter by 15 feet deep tank will be adequate, having a volume of 12,700 gallons. The neutralizers will be made of FRP (fiberglass reinforced plastic) material.

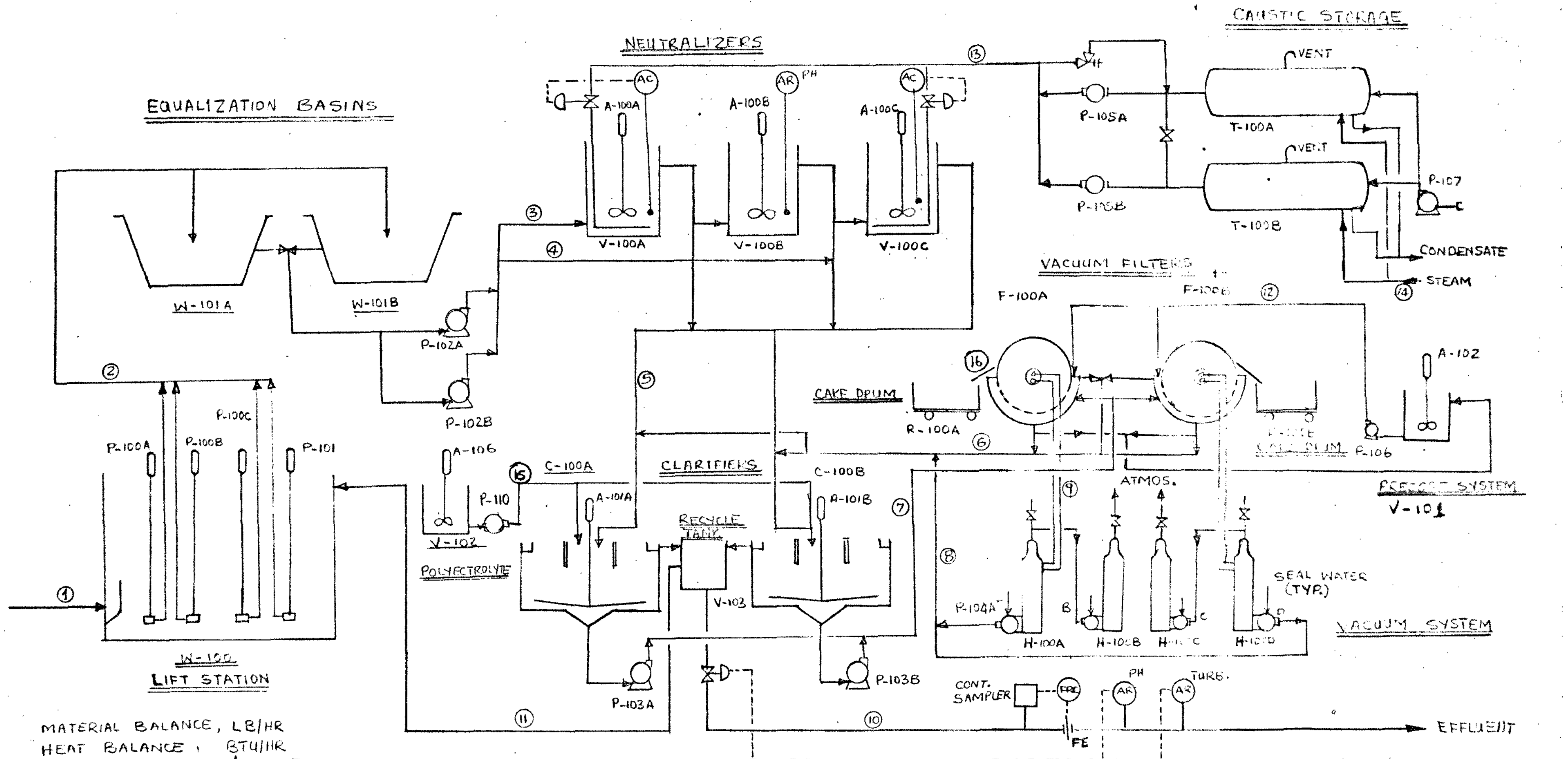
iv) Clarifers: From the test results in Chapter 2, surface loading was established as slope $\frac{ft}{min.} \times 7.48 \frac{gal}{ft^3} \times 1440 \frac{min.}{day}$

For this type of waste, surface loadings as high as 900 can be used. On this basis, the slope will be about .825 feet per minute. Therefore, surface area of clarifer will be 2.23 x 10^6 gallons per day times 1/900 gallons per day per square foot equals 2480 square feet, that is 1240 square feet for two clarifers, and diameter is 40 feet. Results of the laboratory tests conducted in Chapter 2, Figure 2, gave a reasonable retention time of 90 minutes. Therefore, the required volume of each clarifer will be 1550 $\frac{gal}{min}$ x 90 min x 1/2 equals 70,000 gallons or 9400 cubic feet. Therefore, depth of clarifer equals $\frac{9400\ ft^3}{1240\ ft^3}$ equals 7.5 feet

Using 8 feet as the depth required for quiescent settling, it is usual to allow for some sludge storage capacity, thus resulting in a practical depth of 10 feet. The final clarifier size will be determined in the vendor tests.

v) Dewatering Equipment: The laboratory tests conducted in Chapter 2, are not designed to provide information for sizing the dewatering equipment, however, they provide information on the degree of difficulty involved in filtering the sludge. For the purpose of the estimate, a theoretical approach backed by experience will be used to establish the equipment size, with the final size being determined by equipment vendor tests.

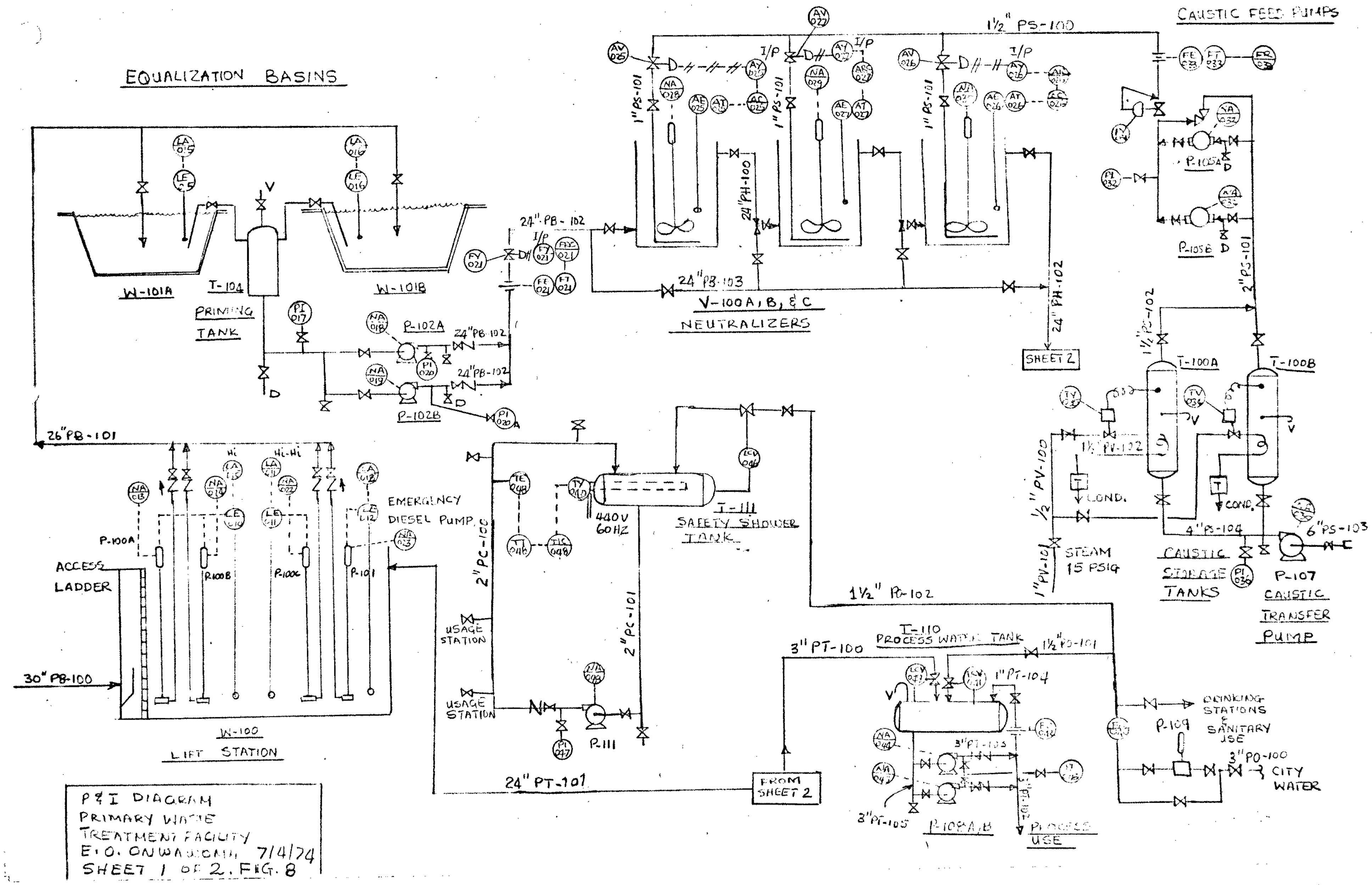
On the average, vacuum filters are more commonly used for dewatering primary waste treatment sludges and the approach here will



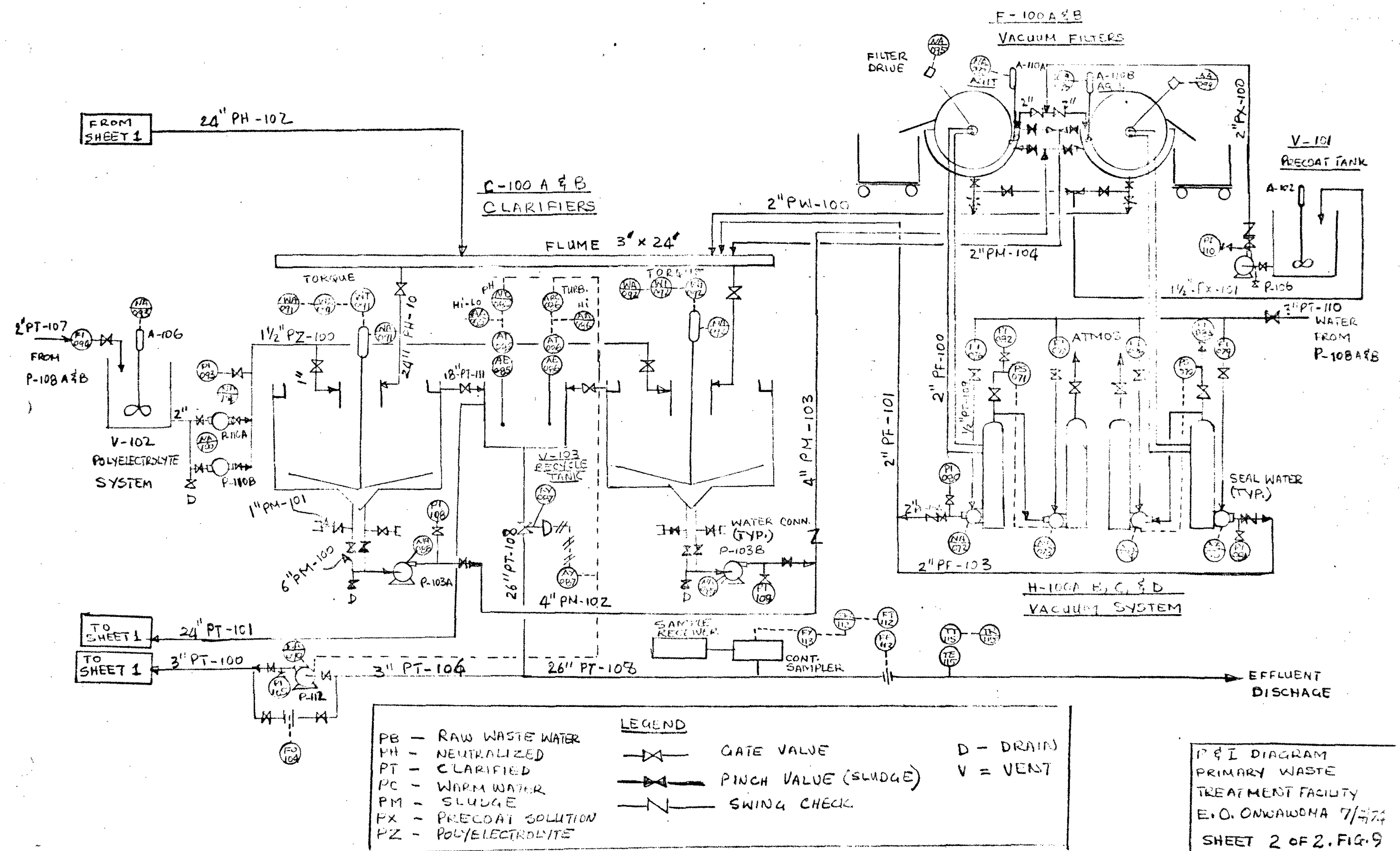
MATERIAL BALANCE, LB/HR
HEAT BALANCE, BTU/HR
BASIS 1550 GALLONS/MINUTE

COMP. \ STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
WATER	770,000	770,000	770,000	0	770,342			15,835	15,835	769,877	0				
SLUDGE						0	16,300								
CAUSTIC													342		
PRECOAT												24			
STEAM														12000	
POLYELECTR.															.04
GPM (AVER.)	1550	1550	1550	0	1551	0	27	26	26	1547	0	—	.9	—	.10

PROCESS DIAGRAM
PRIMARY WASTE
TREATMENT FACILITY
E.O. ONWAWOMA 7/2/74
SHEET 1 OF 1. FIG. 7



P&I DIAGRAM
PRIMARY WASTE
TREATMENT FACILITY
E. O. ONWAUJOMA 7/4/74
SHEET 1 OF 2. FIG. 8


FROM SHEET 1
24" PH-102
C-100 A & B
CLARIFIERS
FLUME 3' x 24'
F-100 A & B
VACUUM FILTERS
FILTER DRIVE
2" PW-100
2" PM-104
2" PX-100
V-101
PRECOAT TANK
A-102
P-106
1½" PX-101
3" PT-110
WATER FROM
P-108 A & B
ATMOS
2" PF-100
2" PF-101
2" PF-103
SEAL WATER (TYP.)
H-100A, B, C, & D
VACUUM SYSTEM
2" PT-107
FROM
P-108 A & B
A-106
V-102
POLYELECTROLYTE SYSTEM
P-110A
P-110B
D
TORQUE
1½" PZ-100
24" PH-101
18" PT-111
HI-LO
TURB.
V-103
RECYCLE TANK
1" PM-101
6" PM-100
P-103A
P-103B
WATER CONN. (TYP.)
26" PT-108
4" PN-102
4" PM-103
TO SHEET 1
24" PT-101
TO SHEET 1
3" PT-100
3" PT-106
P-112
SAMPLE RECEIVER
CONT. SAMPLER
EFFLUENT DISCHAGE
LEGEND
PB — RAW WASTE WATER
PH — NEUTRALIZED
PT — CLARIFIED
PC — WARM WATER
PM — SLUDGE
PX — PRECOAT SOLUTION
PZ — POLYELECTROLYTE
GATE VALVE
PINCH VALVE (SLUDGE)
SWING CHECK
D — DRAIN
V = VENT
P & I DIAGRAM
PRIMARY WASTE
TREATMENT FACILITY
E. O. ONWAWOMA 7/74
SHEET 2 OF 2. FIG. 9

be to use a vacuum filter. The normal design of vacuum filters for heavy metals hydroxides allows 3.5 to 8 pounds per square feet per hour rate of wet cake production when a filtering aid is used. Therefore, to establish the size of the vacuum filter, let us use 6 pounds per square feet per hour. Earlier in this Chapter, was established a wet cake production rate of 465 pounds per hour. Therefore, the surface area required will be: $465 \frac{lb}{hr.} \times \frac{1}{6 \ lb/sq \ ft/hr} =$ 77.5 sq. ft.

This area is based on continuous filtration which is not always the case since the filter has to be washed and precoat layer applied. A 20% increase in the filtering area calculated, will be adequate for this down time, resulting in a filter area of 93 square feet. Allowance is usually made for a spare filter to account for down-time in repairs like filter cloth changes etc. An alternate to sparing the filters, is to build a sludge storage capacity into the clarifers but the inability to determine precisely how long the filter could be down makes it very difficult to estimate the storage capacity. In the design under discussion, a spare filter will be provided. The actual physical size of the filter will be determined by the vendor. The actual cost of the vacuum filter is directly related to the area provided, (between 50 and 300 square feet). The filter drum will be made of polyester material.

C. Miscellaneous Equipment Selection

Under this paragraph, only brief reference will be made to the other equipments associated with this job because they are standard in the process industry.

Pumps: All pumps for the raw waste, sludge and caustic solution will be rubber lined steel construction. All the other pumps are 304L stainless steel construction.

Tanks: The caustic storage tanks are rubber lined steel construction. All the other tanks are 304L stainless steel construction.

Pipes: Raw waste water line, neutralized waste line, sludge line and caustic solution line will be FRP* and PE** pipe. All other pipe lines will be steel pipe except for the sewer lines which could possibly be FRP, PE or vitrified pipe.

Instrumentation: All primary sensors, transmitters, controllers and recorders will be electronic and the output to the final control element will be pneumatic.

D. pH Control System

The pH control system, consists of the pH electrode, the pH transmitter, the controller and the caustic solution control valve. The selection of the components of the systems depends on the individual characteristics of the components, as well as those of the neutralizer and the associated piping. The titration of the

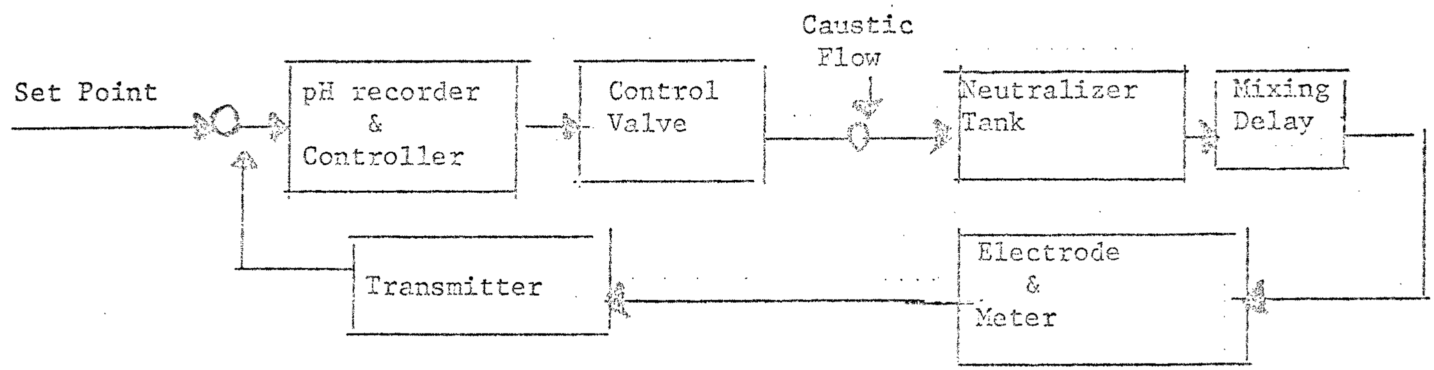
FRP*- Fiber glass Reinforced Plastic
PE** Polyethylene

neutralization of an acid with a base, shows a very sharp rise at portions of interest with an increase in several units of pH with a very small amount of neutralizing agent addition. This pecular nature of pH systems combined with the fact that unlike temperatures, pressures and levels, pH responses are nonlinear, makes an accurate pH control system design difficult to achieve. This difficulty is reflected in the use of three neutralizing tanks, the first tank serving as the reaction stage. The second tank ensures the complete consumption of the neutralizing agent added in the first tank with the third tank used to trim the pH to the neutralization point of 8.5.

A proper pH control system design, is therefore the prerogative of an instrument engineer and our discussions here will be limited to reduction in the total system lag to improve the response time of the system. A typical pH control system block diagram is shown in figure 10.

A change in waste water flow or concentration, would require a change in flow of the caustic solution and consequently the pH of the contents of the neutralizer tank. A quick response of the control components for the pH is highly desirable since a long time lag would result in system instability due to a corrective action being taken long after the waste input change. To ensure an appropriate response time, the whole system has to be evaluated beginning with the design stage in consultation with the instrument

Figure 10. pH Control System Block Diagram



engineer. The important design variables include:

a) Variations in waste flows and concentrations. The design of an equalization basin to hold at least a 24 hour waste water, ensures relatively constant feed concentration to the neutralizers while a flow control upstream of the neutralizers ensures feed flow changes within permissible limits.

b) The neutralizer hold up time (retention time). This plays a very important role in the overall stability of the pH control system because for a constant feed an increasing neutralizer size increases the hold up time and the damping of pH fluctuations. This means that a smaller proportional bands and higher controller gain can be used to reduce the magnitude of the maxium error referenced to the set point. The increase in the neutralizer size, results in mixing delay (in addition to increased cost of the neutralizer tank) which increases the response time of the system. A balance therefore, must be established between these two opposing effects.

c) Mixing time in the neutralizer tank. This is a variable which depends on the size of the neutralizer tank and the speed of the agitator in the tank. The larger the tank the longer the mixing time, but the higher the agitator speed the shorter the mixing time. On this basis, for a given tank size, preference should be given to higher agitator speeds especially when this does not affect the flocculation pattern of the metal hydroxide formed during neutralization. Turbine agitators which run at speeds of about 300 revolutions per minute seem to be adequate for neutralization process.

d) pH electrode and transmitter time constants. These are generally of smaller magnitude compared to the overall system time constant (or lag) but reduction of this time, would improve the response of the system. By positioning the pH electrode at the exit of the neutralizer, the pH electrode sampling (reaction) time is reduced. The transmitter time constant is fixed and the best that can be done is to locate it as close as possible to the pH controller.

e) Reagent control valve. This also is an important variable in the overall control system. Like the other control components, it is characterized by its own lag time. This lag time can be reduced by installing positioners on the control valves and locating the valves as close as possible to the neutralizing tank. The selection of the control valve is also very important because it influences greatly the controllability of the system pH. An improperly sized valve would result in excess (oversized) or deficit (undersized) of neutralizing agent being added when the system pH calls for addition of the neutralizing agent. The titration curve for a representative sample of the waste water, gives a clear indication of the quantity of the neutralizing agent required to reach the control pH level. The control valve should then be sized to provide this average amount of neutralizing agent at about 75 to 85% valve opening. An equal percentage valve, is best suited for this type of control.

f) The controller. In a pH control system such as the one under discussion, the controller should be the last component to be selected. This is because, its performance depends on the collective effects of the other control components of the system in addition to the process characteristics. The overall closed loop gain of the system and consequently the gain of the process must therefore be established before the controller characteristics can be determined. While some writers argue that a multimode controller is hardly better than a simple on-off controller for pH control systems where the retention time in the tank is in excess of about ten (10) minutes; it is usually a cheap insurance against producing off specification effluents to use a multimode controller at all levels of retention times. This is becuase, the ability to change the reset and derivative actions provide additional flexibility in adjusting the controller for fast system recovery from load changes.

In the design of the pH control system of the primary waste treatment facility proposed in this thesis, the time constants and the system lags have been kept to within reasonable limits by:

i) Providing 48 hours waste water storage capacity at the equalization basins to attenuate the effects of variable waste concentration and waste water feed to the neutralizers is controlled to obtain an approximately constant feed rate.

ii) The hold up time (retention time) in each of the three (3) neutralizers in series, has been held to about seven (7) minutes. This is a compromise between pH damping due to fluctutions and long mixing time lags.

iii) The mixing time lag, has been reduced by using a six-blade turbin agitator at a speed of 300 revolutions per minute.

iv) The pH electrode sampling time lag has been greatly reduced by locating the electrode directly inside the neutralizer but close to the exit. The pH transmitter time lag has been kept to a minimum by locating in it the control panel with the pH controller.

v) The control valve time lag has also been reduced by the use of a positioner on the valve and the controllability of the system improved by selecting an equal percentage valve which provides an average amount of required neutralizing agent at the control pH point of 8.5 at 80% valve opening.

vi) A multimode controller with proportional band, reset and direvative actions is selected for the pH control at the first and third neutralizers where caustic is added. The pH of the waste in the first neutralizer will be controlled at 4.5 and at 8.5 in the third.

Table 6. Process Equipment List

Equipment No.	Description	Size or Capacity	Material of Contr.	Motor HP	Motor RPM
W-100	Lift Station	20'x25'x15'D	Acid brick lined	-	-
W-101A	Equa. basin	150'x250'x10'	Rubber lined	-	-
W-101B	Equa. basin	"	"	-	-
T-104	Priming tank	4'x8'	304 SS	-	-
V-100A	Neutralizer tank	12'x15'	FRP	-	-
V-100B	Neutralizer tank	12'x15'	FRP	-	-
V-100C	Neutralizer tank	12'x15'	FRP	-	-
C-100A	Clarifier	40'x10'	Epoxy line st.	-	-
C-100B	Clarifier	40'x10'	Epoxy line st.	-	-
F-100A	Vacuum filter	93 Ft^2	Polyester drum	-	-
F-100B	Vacuum filter	93 Ft^2	Polyester drum	-	-
T-100A	Caustic storage tank	70,000 gal.	Rubber line st.	-	-
T-100B	Caustic storage tank	70,000 gal.	Rubber lined st.	-	-
V-102	Polyelectrolyte tank	500 gal.	304L SS	-	-

V-101	Precoat tank	1000 gal.	304L SS	-	-
T-110	Process water tank	1000 gal.	304L SS	-	-
T-111	Safety shower tank	600 gal.	304L SS	-	-
H-100A	Vacuum receiver tank	to be	-	-	-
H-100B	Vacuum discharge snubber	furnished	-	-	-
H-100C	Vacuum receiver tank	by filter	-	-	-
H-100D	Vacuum discharge snubber	vendor	-	-	-
R-100A	Dewatered sludge receiver	5 tons	-	-	-
R-100B	Dewatered sludge receiver	5 tons	-	-	-
V-1003	Clarified water recycle tank	8,000 gal.	-	-	-
A-100A	Neutralizer agitator (turb.)	-	Rubber lined st.	7	1750
A-100B	Neutralizer agitator (turb.)	-	Rubber lined st.	7	1750
A-1000	Neutralizer agitator (turb.)	-	Rubber lined st.	7	1750
A-110A	Filter sludge agitator	-	"	3/4	"
A-110B	Filter sludge agitator	-	"	3/4	1750
A-102	Precoat Agitator	-	304L SS	1/2	"
A-106	Polyelectrolyte tank agitator	-	304L SS	1/4	1750

A-101A	Clarifier rake	–	Rubber lined st.	5	1750
A-101B	Clarifier rake	–	"	5	1750
P-100A	Lift station pump	800 G.P.M.	Rubber lined st.	35	"
P-100B	Lift station pump	"	"	35	"
P-100C	Lift station pump	"	"	35	1750
P-101	Emerg. lift station pump	1600 G.P.M.	"	60	"
P-102A	Waste water feed pump	800 G.P.M.	"	30	"
P-102B	Waste water feed pump	800 G.P.M.	"	30	"
P-103A	Sludge fee pump	40 G.P.M.	Rubber lined st.	3 1/2	1750
P-103B	Sludge fee pump	40 G.P.M.	Rubber lined st.	3 1/2	1750
P-112	Proc. water tank feed pump	100 G.P.M.	304L SS	6	1750
P-108A	Process water feed pump	100 G.P.M.	"	6	1750
P-108A	Process water feed pump	100 G.P.M.	"	6	1750
P-10g	City water feed pump	30 G.P.M.	304L SS	2 1/2	1750
P-111	Safety shower circ. pump	10 G.P.M.	304L SS	1	1750
P-107	Caustic transfer pump	1500 G.P.M.	Rubber lined st.	75	1750
P-105A	Caustic feed pump	1.5 G.P.M.	Rubber lined st.	1/2	1750
P-105B	Caustic feed pump	1.5 G.P.M.	Rubber lined st.	1/2	1750

P-110A	Polyelectrolyte feed pump	1. G.P.M.	304L SS	1/4	1750
P-110B	Ployelectrolyte feed pump	1. G.P.M.	304L SS	1/4	1750
P-106	Precoat feed pump	10 G.P.M.	304L SS	1	1750
P-104A	Vac. receiver tank pump	40 G.P.M.	304L SS	2 1/2	1750
P-104B	Vac. snubber tank pump	-	304L SS		1750
P-104C	Vac. receiver tank pump	40 G.P.M.	304L SS	2 1/2	1750
P-104D	Vac. snubber tank pump	-	304L SS		

The process equipment sizes shown are subject to change when vendor bids are received and should therefore be considered as preliminary.

CHAPTER 7

MECHANICAL DESIGN

The mechanical design phase of the project, deals with the transformation of the information contained in the process flow sheet and *P & I diagrams into construction drawings. This phase of the project is as important as the process phase because the success of many other phases of the project depends on the quality of information developed here. For example, civil design and final process design depend on the plant layout and equipment arrangement.

To achieve the objective of this phase of the project, plant layout, equipment arrangement, piping arrangement, piping isometrics, material list and take off drawings must be prepared. These documents will then serve as references for, a) the design of equipment and piping supports, b) determining the nature of flows - gravity or forced, c) determining space requirements for the process component, d) preparing purchase requisition for piping and valves, e) preparing the construction bid package.

Plant Layout and Equipment Arrangement Drawings

This is the first set of drawings that usually must be prepared because, they lay out the proposed site for the facility and locate the various equipments and accessories required for the facility. The layout drawings must show all buildings, their sizes

*P & I is Piping and Instrument diagram.

and descriptions, location of floor drains, exact equipment locations, equipment sizes and elevations, aisles and bays for material handling and equipment maintenance, and classification of areas where applicable. The nature of these drawings is such that a certain amount of reliable information must be available to make the drawings reasonably accurate for other engineering work that must depend on them. This information includes:

a) General location of the site with respect to adjacent properties and installations.

b) Nature of the soil with respect to load bearing capacity.

c) Process flow sheet which shows all equipment and their operating conditions.

d) Vendor prints for the physical size and nozzle orientation of the equipment and associated nozzle size and orientation.

e) Clients preferences or standards with respect to spaces between installations, access to equipment, operating philosophy etc.

Piping Arrangement and Isometrics

The main objective of piping arrangement and isometric drawings is to provide information for materials take-off, piping fabrication, and piping support design. In preparing these drawings, consideration must be given to pressure loss in pipe fittings especially elbows, and economical arrangement of piping for ease of support, piping subsection flexibility, and accessibility to valves and instruments requiring maintenance.

Piping isometrics are complements to the piping arrangement drawings and they generally provide details of the pipe routing, section by section. These are the drawings the pipe fitter uses to assemble the piping and piping subassemblies in the field.

For the primary waste treatment facility being discussed in this thesis, the piping arrangement and isometrics, do not differ from those of other liquid handling process plants at ambient conditions. However, the sludge lines must be fitted with break flanges for cleaning the lines and long radius elbows to reduce the incidence of line plugging.

Piping Bill of Materials (B/M)

With the piping arrangement and isometric drawings prepared, material take off lists (B/M) are then prepared. An appropriate grouping of the items in the B/M is then prepared for piping requisition release and subsequent purchase order placed. A typical B/M form is shown below in Figure 11.

Made by ____________________ date ____________________ Project Engineer ____________________

Checked by ____________________ date ____________________ Project Auth. No. ____________________

Line No. & Size	From Equip.	To Equip.	Quantity									
			Pipe	90° Ell	45° Ell	Tee	Flange	Gasket	Valves			
									Gate	Globe	Pinch	Check

Plant section ____________________

Issue No. ____________________ Sheet No. 1 of N

Figure 11 Bill of Material Form

CHAPTER 8

EQUIPMENT PROCUREMENT

Equipment procurement, forms an important activity of a project because the construction planning and scheduling cannot be realistically done unless equipment delivery dates are known. In most process plants, equipment deliveries feature prominently in the critical path of the project schedule. It is not therefore surprising that equipment procurement is planned long before project approval and detailed engineering phases of the project.

Formal equipment procurement normally involves preparation of equipment specifications, bid analysis, final purchase order releases, vendor prints schedule, equipment inspection and test at the vendor shop, and expediting. These functions are not all under the project engineer's control although he has the responsibility of ensuring that the functions are properly carried out and within the schedule. For example, purchase orders are issued by the purchasing department although the project engineer must sign them before they are released to the vendors.

Equipment Specifications

The preparation of equipment specifications focuses on the process conditions the particular piece of equipment is required to meet in addition to contract terms between the vendor and the equipment purchaser. The contract terms are usually standardized with many companies and will not be discussed further here.

The write up of the equipment specification, requires knowledge of its function in the process, knowledge of what is available with vendors, and the approximate cost differential for accessories. Unless where absolutely necessary, equipment specifications should be written around standard off shelf designs since deviations from standard designs would require additional engineering by the equipment vendor and a disproportionate increase in equipment cost. However, for special equipment or standard equipment designs requiring modifications, sufficient details must be spelled out in the specification to prevent unpleasant surprises in the future.

For a simple process like the primary waste treatment facility being proposed in this thesis, the equipment can usually be grouped for the purposes of writing specifications more effectively. Such grouping will involve:

a) The basins and lift station

b) The storage vessels

c) The reactors (neutralizers and clarifiers)

d) The special equipment (vacuum filters)

e) The pumps

f) Instrumentation - control and measuring components

g) Electric power supply components

h) Pipes, valves etc.

i) Miscellaneous items like materials handling equipment etc.

The project engineer provides the process input for:

i) The civil engineer to write up specifications for item (a).

ii) The mechanical engineer to write up specifications for items b, c, d, e and h.

iii) The instrument engineer to write up specification for item f.

iv) The electrical engineer to write up specification for item g.

The involvement of the project engineer goes far beyond coordination. He prepares the initial sketches for the basins, life stations, storage vessels, special equipments, head and suction requirements for pumps etc. which will be used by the specialized engineering groups to produce the final specifications which then will be sent out to vendors for bids or quotations.

Bid Analysis and Purchase Order

Bid analysis is the comparison of vendor quotations for a particular piece of equipment before a purchase order commitment is made. This is because, many companies have the policy of soliciting bids from three or more vendors for a particular piece of equipment to ensure equipment purchase at the best possible terms. Even when only one quotation is received because other vendors decline to quote on the equipment or because only one vendor is qualified to bid on the equipment, the quotation must still be evaluated to determine whether it meets the conditions spelled out in the requisition.

A typical bid analysis will evaluate the vendor quotes on the following basis:

a) Whether the equipment offered meets the specifications.

b) Whether alternates are offered where the specification cannot be met exactly.

c) Whether the quotation includes recommend accessories and spare parts.

d) The cost of the equipment and extras such as spare pump impellers etc.

e) The equipment delivery date.

Depending on the type of equipment, the analysis may include the evaluation of critical dimensions or parts e.g., seals and bearing on moving parts, noise and vibration levels, special features of the equipment which are advantageous for its use but were not included in the specifications, corrosion allowances and the fabrication of material of construction of the equipment. These are the major parameters usually evaluated before a commitment is made with a particular vendor by issuing a purchase order. Once the equipment is on order, further involvement is limited to equipment expediting and possible change orders where that is necessary.

Expediting and Vendor Prints

Expediting can be defined in simplest terms as the follow up of equipment purchase order to ensure vendor compliance with equipment drawings tranmittals on schedule and ultimate equipment delivery on dates specified. This activity like the rest of the equipment procurement activities, is integrated within the purchasing department.

The engineering department is kept informed bi-weekly or monthly on the status of the equipment by means of reports issued by the purchasing department. This communication link between engineering and purchasing is very important because changes on equipment delivery dates or drawing transmittals would disrupt design and construction schedules, and engineering must be informed in time to allow for appropriate counter measures or schedule adjustments to be made.

The expediting group in performing its activity, must see to it that the vendor drawings and documents received, are transmitted promptly to the various engineering groups who must review them. In addition, the responsibility for returning the reviewed drawings and documents to the vendor on time, rests with the expediting group. Thus the expediting group functions as a direct linkage between the engineering groups and the vendors.

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CHAPTER 9

CONSTRUCTION

Chapters 1 through 8 have dealt with the collection of process data, application of these in process design and the procurement of process materials and accessories. This chapter will deal with the application of these data and materials in the "field" to physically complete the process facility. Process plant construction covers so much ground that every aspect of it cannot be effectively discussed in this thesis which considers construction as one of the many major phases of a process plant facility. Therefore, the objective here will be the discussion of the steps which lead to construction activities and the control of these activities.

As a result of the urgency in completing a job and the fact that the construction phase of the project is the single most time consuming phase of the entire project, the construction activities usually overlap the three most significant phases proceding construction, viz, process design, mechanical and material procurement. Thus construction activities which do not involve extensive process and mechanical design work, do in fact run parallel with the design phases of the project. These activities generally include site preparation, sewer work, building foundation etc. The civil contractor is usually the initial contractor and since he is seldomly a mechanical contractor as well, it often happens that two or more contractors are engaged at the same time for a particular plant facility. The job of coordinating their efforts for maximum productivity, is greatly simplified by the terms of the contract.

Construction Package For Bid Solicitation

A construction package is an essentially complete documentation of the scope of a process facility in terms of the extent of work involved, relevant construction drawings and documents. For the primary waste treatment facility being proposed in this thesis examples, the construction package will include the following:

1. All engineering drawings - site topography and map, soil bearing graphics, plot plan, equipment arrangement, piping arrangement and elevations, isometrics, process flow sheet, piping and instrument diagram and vendor drawings.
2. Documents - specifications for equipment, piping, instruments, bill of materials, vendor installation instructions, purchase orders, expeding schedule, inspection and test results at vendor shop, and overall project planning schedule.
3. Owners field assistance - resident engineer to assist contractor in interpreting drawings and documents, initiating changes and coordinate the construction efforts.
4. Contract type - lump sum or cost plus fee and any variations of these. The type of contract chosen depends on the owners engineering organization, policy and the overall state of the economy. Well organized corporate engineering groups in a company usually possess the talents to supervise the contractor

closely and a cost plus fee contract will be profitable despite the greater owners risk involved. On the other hand, a lump sum contract provides a greater profitability for the owner in an inflationary economy despite the need for a more detailed engineering design and a much harder negotiation with the contractor.

Bid Analysis and Contract Award

This involves an evaluation of the cost to construct the facility and the contractor organization. Construction bid packages as a rule, are usually sent to three or more prequalified contracting companies who have established reputations acceptable to the owner of the facility. This reduces the task and time involved in reviewing the bids received and awarding the contract. Thus the bid analysis reduces to that of cost to construct the facility, completion schedule and comparison of the qualifications of the contractors (prequalified) in terms of, a) business character, b) type of organization and management quality, c) experience in type of work involved, d) financial standing, e) labor policy, f) type of insurance policy coverage, g) flexibility in dealing with changes, additions and omissions. On these basis, a contractor is selected and contracts are awarded with contract agreement signing.

The contract agreement, spells out the specific terms of the agreement between the owner and the contractor. These terms, usually include;

a. Agreed construction completion date.

b. Field changes - additions, omissions and authorization.

c. Subcontract work.

d. Supervision or inspection by owner.

e. Type of union labor.

f. Personal injuries and property damage.

g. Type of insurance policy coverage.

h. Factors beyond human control e.g. bad weather etc.

i. Method and schedule for construction progress report.

j. Payment schedule.

k. Contract termination and or cancellation.

l. Construction completion and acceptance criteria.

These are the most important terms usually written into a construction contract. The extent and ramifications, depend usually on the type of contract, viz, lump sum or cost plus fee.

No attempt has been made in this thesis to present the information in a logical contract format or use the normal legal terms for contracts because such an attempt would be a duplication of the standard contract forms already in existence in nearly all major companies. However, it is the belief of the writer that the grounds covered here, represent the major elements of a construction contract in the field of construction contract dealings which need to be known to perform a fairly good job.

Construction Schedule and Progress Report

Like any major phase of a project, field construction planning and scheduling is very important, because it provides for orderly execution of the construction phase of the project by providing for the contractor and owner's management means to effectively control the field activities. The control and planning of the day to day construction activities and coordination with the engineering and materials procurement groups, is generally possible only through proper preconstruction planning and scheduling.

While the process owner usually relies on the construction management to draw up a good plan and schedule for the field work, he retains the responsibility to ensure that a realistic schedule has been made especially in a cost plus fee type of contract where efficient work means savings for the owner. Regardless of the type of contract however, low efficiency means delay and added cost in completing the work.

A proper control of the construction schedule is called for if planned milestones must be met. This is achieved by setting up a cost and progress report system which serves as a barometer for matching completed work against planned cost. This is the only way to detect failure to reach milestone points. Equally important, is the milestone point selection and the intervals for progress report. It is the general practice to choose the milestone points as close together as practical because this makes progress reporting more substantiative and more appealing to the management (owner and contractor). In addition, milestone points not too far apart (corresponding to progress report period) allow for early detection of problems or negative trends which can be corrected with less difficulty and cost than at much later dates. More details of this topic have been covered in Chapter 5, entitled "Planning, Scheduling and Control".

The field contruction schedule and progress report can be presented in various formats, but, all have the same common objective which is a definite well thought out plan of executing the construction phase and monitoring the work progress. For the primary waste treatment facility being proposed in this thesis, the construction "S" curve and bar chart will be used as the field construction schedule and control, as shown in Figure 12. This is a very simple graphical approach used to represent the very extensive pre-construction planning and scheduling which is necessary to coordinate the several thousand activities involving efficient work execution and materials availability. Although the details of pre-construction planning and scheduling varies from job to job and from organization to organization, the need for a master plan and schedule which relates field construction work, craft and labor requirements and material availability cannot be ignored.

Figure 12 shows the bar chart and the curve. The bar chart shows the schedule and actual duration of each major activity of the field construction while the "S" curve shows the scheduled and actual progress of the field construction activities as a percentage of the overall field construction work. A supplement to the chart and curve is a chart for construction craft and material availability which are the elements required to meet the schedule.

Construction Participation by the Owner

The elements for proper field construction control to maintain acceptable efficiency and meet scheduled completion date, have been established in the preceeding subsection. The emphasis in this subsection will be the application of the monthly progress report by the process plant owner to effectively supervise the contractor to ensure construction completion as scheduled.

The role of the process plant owner in field construction varies from that of ensuring that the plant is built according to specification and completed as scheduled to that of active participation in the day to day construction planning and coordination. The type of involvement, is usually determined by the type of contract. A cost plus fee type of contract increases the owner's risks but has as a benefit lower field construction charges. This calls for active participation by the owner to ensure minimum cost without sacrificing quality. A lump sum contract, requires monitoring only to ensure compliance with specifications and scheduled completion date.

For lump sum contracts where minimum supervision is required by the owner, a single resident engineer in the field is all that is required. His principal functions are those of coordinating materials furnished by the owner with those furnished by the contractor to ensure continuity of field construction work. In addition, he must handle field changes, analyze and transmit to the owner construction progress reports, arrange for contractor payment as the work progresses, and resolve descrepancies in specifications and construction drawings. He does not get involved in the day to day construction work planning and control. This type of contract is most suited for small to medium sized companies where specialized construction and engineering departments are not usually available.

In a cost plus fee type of contracts the owner is directly involved with all the activities of the field construction. The day to day planning, scheduling and control of construction work must be jointly planned by the contractor and owner. The owner field engineers must coordinate construction material deliveries and movements, participate in construction plan and schedule changes, in the distribution and forecast of construction craft requirements, in the initiation and approval of specifications and construction drawings changes, and in labor related problems like overtime approval. The monthly progress reports must be reviewed by the owner's engineers to determine whether construction is progressing as planned both in percentage of total work completed and cost, and whether these deviate negatively from the plan. In addition the owner with the consent of the construction contractor, must initiate changes in the schedule to correct for these deviations. These involvements, are in addition to those mentioned under lump sum contract. In summary, a complete interface between the owner and the contractor is required through out the construction work. Another feature of this type of contract, is the absence of the need for complete construction drawings and documents, thus saving some money in the engineering designs. Large companies with specialized construction and engineering departments are best suited for this type of contract.

Construction Completion

Construction completion can be defined very simply as the completion of all construction work as defined in the original scope of the work and agreed to in the contract. However, what constitutes completeness of work varies from one contract to another, and the owner therefore must define very clearly in the scope of work description the degree of completeness the contract must cover so as to eliminate any ambiguities or doubts which can only cause disputes at the close of the field construction.

While it is impossible here to go into the details of the legal definitions of what constitutes completeness, it can be said that for most contracts, construction completeness involves as a minimum, the following:

a) Physical installation completeness of all equipments, piping, instruments, electrical, buildings, winterizing, insulation, painting, surface protection of equipments, piping and structures, roads and supporting facilities.

b) Rotating equipment check out as to the direction of rotation, alignment and vibration level.

c) Lubrication and adjustment of mechanical equipment.

d) Water flushing, leak testing and drying of all equipment and piping.

e) Electrical equipment check out as to polarity, circuit integrity and resistance measurement.

f) Instrument calibrations.

g) Changes during startup to allow proper operation.

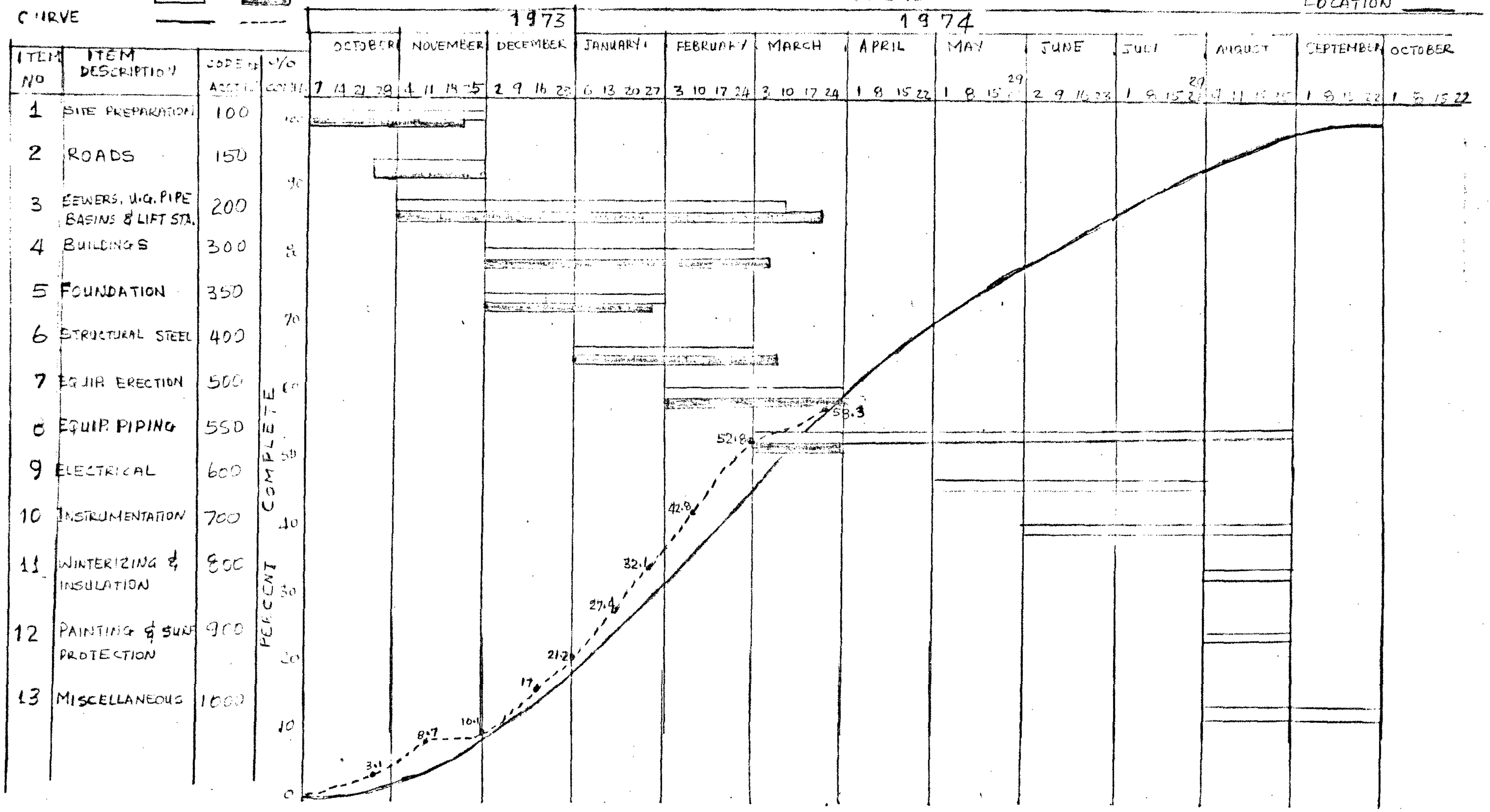
It may also include operating manuals, initial startup, general yard cleaning with removal of construction equipment and facility.

CONSTRUCTION SCHEDULE AND PROGRESS REPORT
UP TO MARCH 29, 1974

PREPARED BY ______ DATE ______ CUSTOMER ______
APPROVED BY ______ DATE ______ PROJ. NO ______
LOCATION ______

FIGURE 12

LEGEND
BAR CHART — SCHEDULED / ACTUAL
CURVE — SCHEDULED (solid) / ACTUAL (dashed)



CHAPTER 10

PERFORMANCE TEST AND START-UP

Plant start-up represents a classical test of the quality of engineering involved in the process plant design. A properly designed process plant, has a better chance of a smooth start-up than a poorly designed one. Plant start-ups present so many problems that they require much effort in planning, scheduling and coordination of preceeding and succeding project phases. Thus engineering, construction and initial plant operation plans must be integrated to ensure start-up within planned schedule and reduce start-up problems associated with improper transition between the various phases of the process facility. The plant start-up activities can be divided into two distinct phases: pre-start-up and actual start-up.

Pre-start-up Phase

This phase incorporates all the preparations and planning for the actual start-up phase. The extent of preparation and planning depends on the type of process, the size of the process facility, and the available knowledge of the process. A simple or well known process of small to medium size, does not generally require very elaborate preparation and planning whereas a complex (or hazardous) or new technology and large size process plants require very elaborate preparations and planning. The primary waste treatment facility being discussed in this thesis, is considered to be a simple, medium sized process facility with well known technology and therefore, does not require very extensive planning and scheduling. However, the need for proper coordination of the preceeding and succeding project phases is the same for process plants since this is the only way of ensuring a relatively smooth start-up which is within the schedule.

In general, pre-start-up planning and scheduling, involves the following:

a) Assemblage of start-up crew - engineers and operators

b) Training of the crew - familiarization with the process and the actual facility through construction follow up.

c) Preparation of operating manual for use in start-up and actual process operation.

d) Start-up spare parts like gaskets, seals, fittings etc.

e) A crew of pipe fitters, electricians and welders

f) Plant inspectors and construction punch list for necessary changes before start-up.

g) A schedule for the exercution of the activities a) to g) listed under "Construction Completion", Chapter 9.

h) The start-up crew is usually composed of:

i) Engineers who were involved in the development, design or will be involved in the operation of the process.

ii) Foremen who will be responsible for the maintenance and operation of the process or who are knowledgeable of the operation of the process.

iii) The operators who are not necessarily experienced in the process but can be trained.

The training of the crew is the responsibility of the plant manager, the process and design engineers. For the start-up engineers who are not very knowledgeable in the process, the training is very extensive, and involves the major reactions of the process, process development background, design philosophy, equipment, instrument and piping specifications, engineering drawings (process flow sheets and piping and instrument drawings), field construction follow up, and involvement in all the start-up activities b) to g) listed under "Construction Completion" in Chapter 9. For the foremen and operators, the emphasis is on activities directly related to the start-up and the actual operation of the facility.

The preparation of the operating manual, is usually the responsibility of the engineering design groups or contractor with the cooperation of the process development group and the operation personnel. The actual degree of participation by each of these people depend on the type of contract. The operating manual in essence contains complete information on the process facility, its major features being;

A) General background information on the process.

B) Detailed description of the process which includes properties of feeds, products, by-products, major process reactions, instruments and controls, waste disposal, specifications for materials of construction, design drawings, material and heat balances and vendor prints.

C) Safety procedures for the process operation.

D) Start-up preparations.

E) Actual step by stem process operation.

F) Utilities

G) Recommended manpower needs for efficient operation of process.

H) Maintenance schedules as recommended by equipment vendors, including spare parts list.

Actual Start-up

Actual process start-up, is the final preparation preceeding production under the assumption that the activities b) to g) listed under "Construction Completion" Chapter 9 have been completed, the process plant is now ready for initial start-up.

This generally involves the use of air, nitrogen or an inert gas for processes designed to handle gaseous feeds and products or the use of water or some other adequate liquids for processes designed to handle liquid feeds and products. The process simulation runs are conducted at conditions of flow rates, temperature and pressures similar to those for which the process plant is designed. The main objectives of these runs, are to establish the:

a) Mechanical functionability of the process equipments at design conditions.

b) Proper instrument settings, responses and system characteristics.

c) Operators confidence in running the process plant.

d) Need for revisions in piping or repairs to ensure proper process operation.

e) Cleanliness of the piping system to avoid product contamination.

A successful completion of the simulation runs, sets the process plant ready for production. At this point, the process facility owner, takes full control of the plant and the project can be termed completed from the engineering point of view, subject only to performance guarantees as determined in the contract stage of the engineering work.

CHAPTER 11

CONCLUSION

The material covered in the preceeding chapters of this thesis, represent a very brief summary of the actual project experience of the author in connection with the design, construction and start-up of a primary waste treatment facility in a major chemical company in the United States of America. Although the presentation is very brief, every effort has been made to cover the major activities associated with this type of process facility and references are presented in the bibliography for those readers who desire more detailed information for the various materials covered herewith.

It is appropriate here to emphasize once more the close relationship that exist between the various phases of an engineering project. As must be obvious at this point, a successful completion of an engineering project within budgeted cost and schedule, depends on proper integration of the various engineering phases and adequate cost control. For example, ill defined process conditions, lead to delays in process design and errors which delay the project completion date as well as cause more expensive start-up. In-complete construction drawings and documents reduce the efficiency of the field construction activities and create need for an expanded field construction coordination. The effects of these on schedule completion date and cost to complete the process facility are similar to the ones mentioned above. These are a few of the very many variables in the project activities which affect the overall project completion date and cost. Therefore, the project engineer or manager whose primary responsibility in an engineering project is the completion of the process facility within the schedule and budgeted cost, must ensure a proper integration of the various phases of the entire project and device appropriate cost control techniques to achieve these goals.

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